QUANTUM CASCADE LASER USER'S MANUAL

Version number 3.0

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3. All other claims such as purchase refund, product reconditioning or damage of any nature, be it direct, indirect or consequential, are expressly ousted.

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5. In case of discrepancy between the manual and terms written in the order confirmation, the order confirmation prevails.

CONTACT INFORMATION

Max-Meuron 1-3
C.P. 1766
CH-2001 Neuchâtel
Switzerland

Telephone:	+41 32 729 9510
Fax:	+41 32 721 3619
Email:	info@alpeslasers.ch
Web site:	`http://www.alpeslasers.ch`

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Preface

This manual is a reference tool for personnel using ALPES LASERS QCLs and electronic equipment. Its purpose is to provide the customer with sufficient information to carry out normal installation and operational procedures. It is not intended to replace or supersede any local directive. Table 1 gives a summary of the content of each chapter.

CAUTION:
All personnel must read and understand this manual before attempting to operate ALPES LASERS QCLs or electronic device. Failure to follow safety instructions could result in death or serious injury.

Chapter	Content
1. Overview	General overview of ALPES LASERS QCLs and Starter Kit components.
2. Safety	Information for ensuring safety during the installation, operation and maintenance of ALPES LASERS QCLs and electronic equipment.
3. Installation	Prerequisites, guidelines and list of connections for the installation of ALPES LASERS equipment.
4. QCL operation	Principle of operation of QCLs, ALPES LASERS datasheet and QCL parameters.
5. Starter Kit Operation	Procedures for setting up the Starter Kit and operating a QCL.
6. Technical specifications	Technical specifications and drawings of ALPES LASERS QCLs and electronic equipment.
7. Maintenance	Procedures for exchanging a laser in the LLH housing and calibrating ALPES LASERS electronic equipment.
Appendices	Informations and procedures for advanced users.

Table 1.: Structure of the QCL User's Manual.

Typesetting conventions

- Table 2 gives a list of the acronyms used in this manual.
- A *boxed item* indicates a hardware setting on an electronic device.

Acronym	Official name	Other name
AR	Anti-Reflection coating	
DFB	Distributed FeedBack (laser)	
EPS	External power supply	laser driver
FP	Fabry-Perot (laser)	
LDD	Laser Diode Driver	QCL pulser switching unit
LLH	Laboratory Laser Housing	
NDR	Negative Differential Resistance	
NTC	Negative Thermal Coefficient	
NS	screwed laser submount	
OEM	Original Equipment Manufacturer	
QCL	Quantum Cascade Laser	
ST	clamped laser submount	
TCU	Temperature Control Unit	
TEC	ThermoElectric Cooler	Peltier cooler
TPG	TTL Pulse Generator	QCL pulser timing unit

Table 2.: Acronyms used in this manual.

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1. Overview

In this chapter, a general overview of ALPES LASERS lasers and equipment is given, as well as a brief introduction to the detection principle and fields of application of quantum cascade lasers (QCLs).

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1.1. ALPES LASERS products

ALPES LASERS manufactures Quantum Cascade Lasers (QCLs) of two types: singlemode Distributed-Feedback (DFB) or multimode Fabry-Perot (FP), which can be operated in two modes: continuous wave (CW) or pulsed. ALPES LASERS lasers are available in different types of packaging, presented in section 1.2. ALPES LASERS developed dedicated electronics to control the temperature and current drive of its QCLs; see section 1.3 for details.

ALPES LASERS constantly develops new QCLs and electronics to satisfy inquiries from its customers. Contact ALPES LASERS to find the best solution for your application.

1.1.1. QCL parameters and performance

All ALPES LASERS lasers are thoroughly tested and characterized. The results are reported in datasheets, which are readily available on ALPES LASERS website. Each QCL is delivered with its datasheet, containing data on singlemode and multimode emission, IV curves, emitted power, maximum operating current and operation temperature. See section 4.2 for details.

1.1.2. QCL geometry

Figure 1.1 shows an ALPES LASERS QCL growth and a laser chip mounted on an NS submount (see section 1.1.3). By convention, the vertical axis of the laser is parallel to the growth direction, as well as the beam polarization (i.e. electric field) and the NS submount screw holes axis. The emission axis is perpendicular to the growth direction and to the edges of the NS submount.

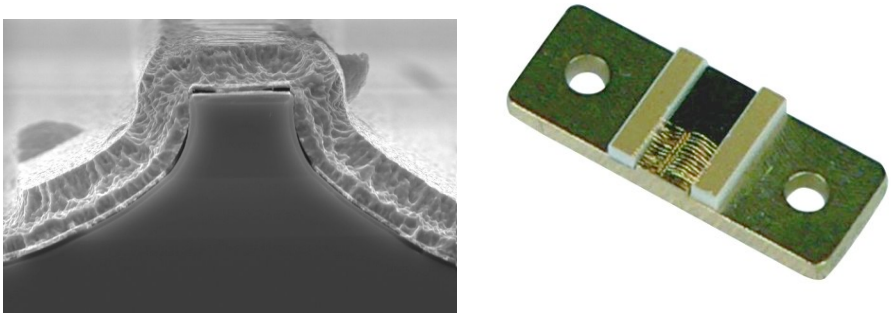

Figure 1.1.: ALPES LASERS QCL growth (left) and laser chip mounted on a submount (right).

The laser chip is soldered to a copper base and is bonded with gold bonds to two AlN ceramic pads, which are themselves mounted on the same copper base, as

shown in figure 1.2. The ceramic pads surface is covered with a gold layer, and their sides have a whitish ceramic color; the golden surface must be positioned upwards. When looking into the LLH from the top, the pad left of the direction of emission is called DN for down, and the right pad UP for up. Only one pad is characterized, as specified in the datasheet. If only one pad is present, it is in the DN position by default.

Polarity

By default, the laser has negative polarity: the cathode is connected to the ceramic pads and the anode is connected to the submount copper plate (see figure 1.2). The laser may be mounted junction down; this is clearly indicated on the laser box. In this case, the laser has positive polarity: the cathode is connected to the submount copper plate and the anode to the ceramic pads.

1.1.3. QCL mounting

ALPES LASERS QCLs can be mounted on two types of submounts:

- ST: clamped mounting
- NS: screwed mounting

The QCL submount can be integrated in a LLH, HHL or in any package designed by the customer. The QCL submount is itself mounted on a copper plate, which lies on a Peltier junction for heat dissipation, as shown in figure 1.2.

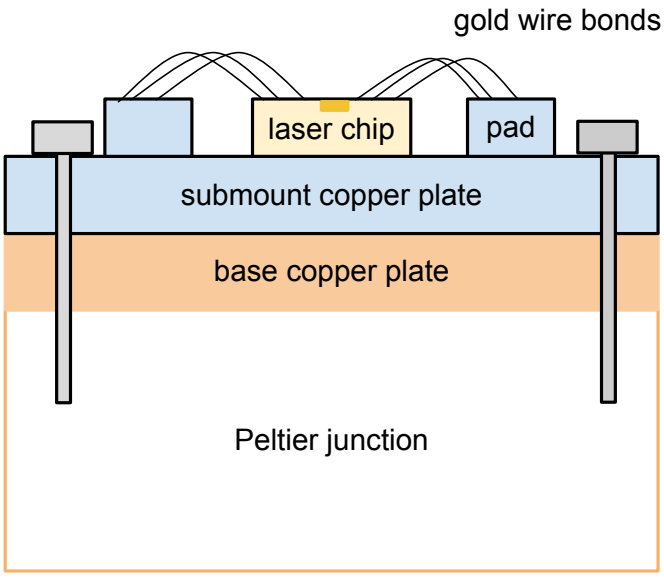

Figure 1.2.: ALPES LASERS QCL NS submount mounted in a HHL or LLH housing.

1.2. QCL housings and packages

ALPES LASERS QCLs can be delivered in 5 kinds of packages:

Chip-on-Carrier (CoC) A laser chip available on stock is mounted on either a NS or ST submount (see section 1.1.3) . These submounts can be integrated into a LLH or HHL housing, or can be sold as an such, to be integrated in a piece of equipment manufactured by the customer.

Laboratory Laser Housing (LLH) The LLH is designed for research applications, and can be cooled down to -30°C with water cooling. With easy laser exchange and compatibility with the Starter Kit, it is the most versatile housing available. All ALPES LASERS available on stock can be used in a LLH housing. See section 1.2.1 for details.

High Heat Load (HHL) The HHL housing is a sealed collimated housing with TEC for CW or pulsed lasers. The optional collimating lens is protected by a plane window, making it ideal for operation in aggressive environments. See section 1.2.2 for details.

TO3 Pulsed lasers are available in TO3 cans, which are smaller and less power-intensive than the HHL packages. TO3 housings are sealed, include a TEC and are available with AR coated lenses for beam collimation or flat windows. Their small size and low dissipation (less than 4W in pulsed mode) make them ideal for integrating the QCL in a piece of equipment manufactured by the customer.

Note: most lasers listed on ALPES LASERS website cannot be mounted in a TO3 housing; address your inquiry directly to ALPES LASERS.

Bare Chips : untested laser chips

1.2.1. Laboratory Laser Housing (LLH)

The LLH consists in a housing including a TEC and encapsulating the QCL chip; it is designed to ease its installation and replacement. Its internal temperature is controlled by a Peltier junction and a PT-100 or NTC temperature sensor, and can go down to less than -30°C. Heat should be dissipated using one of the setups described in section 3.1.2. The LLH temperature is controlled by the TCU (see section 1.3.1).

Figure 1.3.: LLH housing.

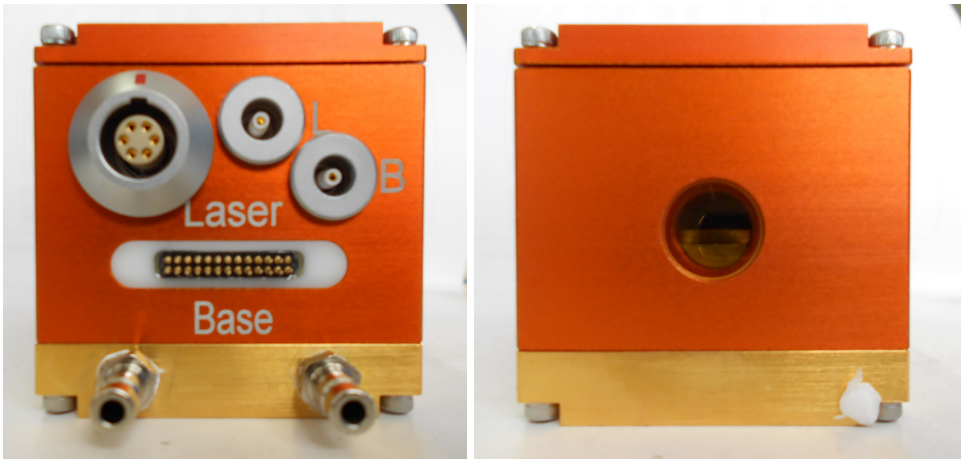

Figure 1.4.: LLH housing connection panel and window.

1.2.2. High Heat Load (HHL) Housing

The HHL housing is much smaller than the LLH and is completely sealed. The HHL contains a Peltier junction and a PT-100 or NTC temperature sensor, which can be controlled by the TCU (see section 1.3.1) or a local temperature control system. Heat dissipation is performed by thermal contact with its copper base; the heat dissipation capacity depends on the operation mode and environmental conditions. The IR beam is collimated through a chalcogenide glass lens and goes through an AR-coated ZnSe window.

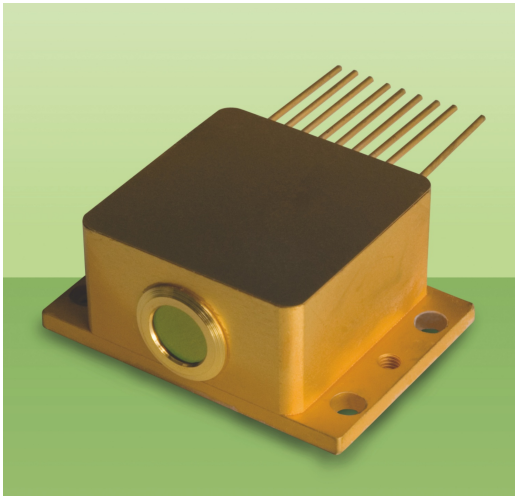

Figure 1.5.: HHL housing.

1.2.3. TO3 Housing

The TO3 housing is a hermetically sealed small-footprint housing designed for integration into commercial devices. It is available in two versions: the TO3-W has a divergent output through an AR coated window, and the TO3-L (shown in figure 1.6) has a collimated output. The TO3 contains a TEC and a NTC temperature sensor. The TEC power is limited compared to the TEC included in the HHL or LLH housing, therefore only pulsed lasers can be encapsulated in TO3 housings.

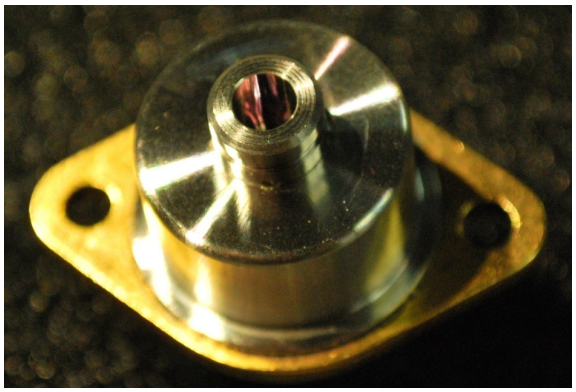

Figure 1.6.: TO3-L housing.

Note: QCLs mounted on an NS submount and controllers of the Starter Kit (see section 1.3) are not compatible with the TO3 housing, therefore encapsulation of a QCL in a TO3 housing is performed upon specific request only.

1.3. Starter kit

The purpose of the Starter Kit is to readily operate an ALPES LASERS QCL. The user must provide an external power supply; see section 3.1 for prerequisites and section 1.4 for recommended peripherals. The kit is delivered with all cables needed to connect the LLH or HHL housing, electronic devices (TCU, LDD and TPG for pulsed operation), power cables and connections for optional water cooling. The installation and connections of the Starter Kit components are described in chapter 3.

CW mode

The Starter Kit shown in figure 1.7 is meant to operate QCLs in CW mode. It consists of the following elements, which are described in dedicated subsections:

- Temperature Controller Unit (TCU), section 1.3.1
- CIL and CTL or CTLm cables for laser driver and TCU, section 3.3

Figure 1.7.: Starter Kit for CW mode operation, shown with laser driver (not included in the Starter Kit).

Note: a CW QCL is very sensitive to electrical surges and instabilities as any conventional bipolar laser diode (telecom NIR laser). It is necessary to use a good quality power supply; see section 1.4 for recommended peripherals.

Pulsed mode

The Starter Kit shown in figure 1.8 is meant to operate QCLs in pulsed mode. It consists of the following elements, which are described in dedicated subsections:

- Temperature Controller Unit (TCU), section 1.3.1
- Laser Diode Driver (LDD), section 1.3.2
- TTL pulse generator (TPG), section 1.3.3
- CPL and CTL or CTLm cables for laser driver and TCU, section 3.3

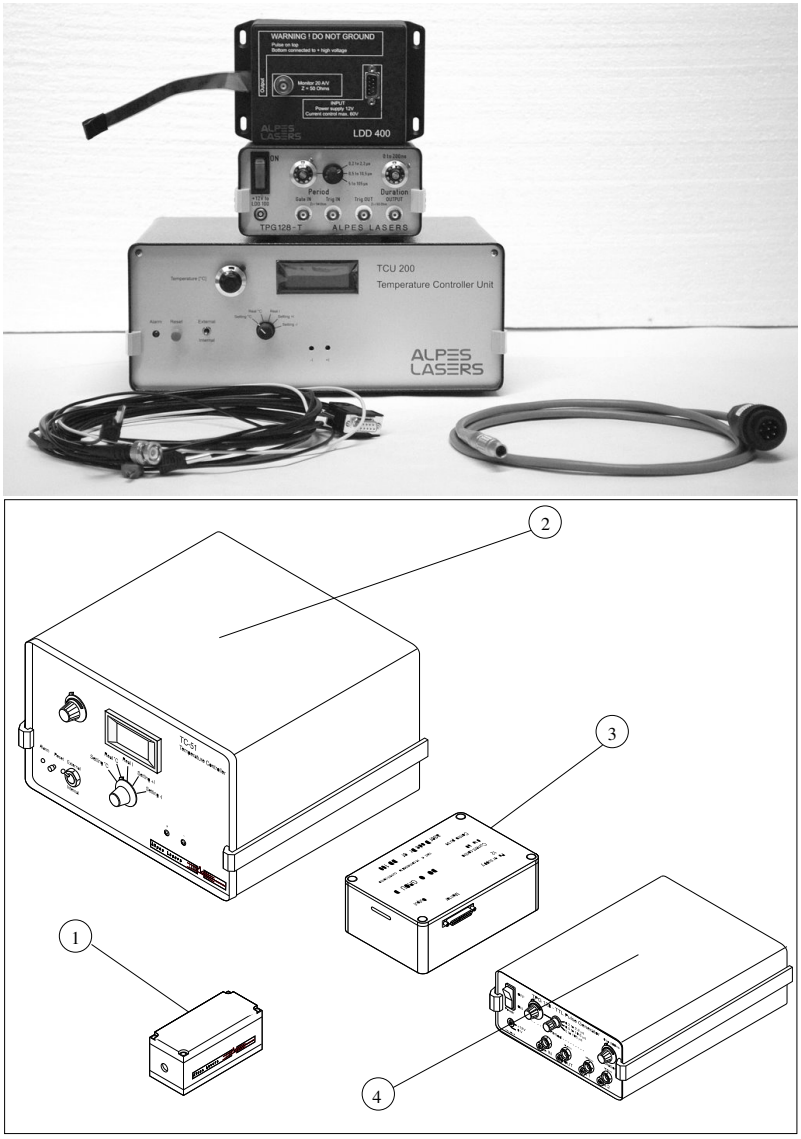

Figure 1.8.: Starter Kit TCU (2), LDD (3) and TPG (4) for operation in pulsed mode.

1.3.1. Temperature Controller (TCU)

The TCU purpose is to control the laser temperature inside the LLH or HHL housing. It powers the Peltier junction and reads the temperature from the PT100 sensor coupled to the laser chip (see section 1.2.1). The TCU internal parameters are set in factory according to its use with a LLH or HHL housing. It maintains a preset temperature using the front panel knobs (internal mode) or from a user supplied voltage (external mode). It also provides an output for real temperature monitoring. The TCU interlock system protects the laser from overheating; see section 5.1 for TCU operation procedures.

Figure 1.9.: TCU front panel.

1.3.2. Laser Diode Driver (LDD)

The Laser Diode Driver shown in figure 1.10 is a switching unit which creates current pulses to drive the laser. The LDD is controlled by a TPG (see section 1.3.3) and powered by an external power supply. It is equipped with a Bias-T for electrical wavelength tuning (see section B.3 for details).

Figure 1.10.: Laser Diode Driver (LDD).

Voltage rating and operating temperature

The LDD is based on dedicated power MOSFETS with compliance with up to 30A and 60V. During operation, the temperature of the case should not exceed 60°C. The LDD electronic card lies on a copper plate and no other means of active cooling is provided. In normal conditions, those temperatures are not reached as the laser operating voltage is of typically 2A, well above the LDD voltage rating.

Laser pulse parameters measurement

Estimated values of the laser pulse parameters (peak voltage, supply voltage, duty cycle, frequency) can be measured through the BNC *monitor* connector with 20A/V shown in figure 1.10. The data provided by the measuring unit is useful for monitoring and surveillance, and to give a rough estimate of current parameters.

Note: the exact measurement of short strong pulses with diodes and averaging circuitry is non-trivial, therefore accurate time and voltage measurements should be performed directly on the LLH or HHL housing through the *laser* and *base* connectors.

1.3.3. TTL Pulse Generator (TPG)

The TPG shown in figure 1.11 is designed to power and control the LDD (see section 1.3.2) by generating TTL pulses on 50Ω. The pulse duration can be set from 0 to 200 ns and the interval between pulses from 200 ns to 105 μs. See section 5.2 for operation instructions.

Figure 1.11.: TTL Pulse Generator (TPG).

1.4. Peripherals

The following devices are recommended as peripherals for operating ALPES LASERS lasers.

CW laser driver : precision laser diode current source such as

- ILX LIGHTWAVE LDX-3232 High Compliance Quantum Cascade Laser Diode Driver (http://www.ilxlightwave.com/propgs/laser-diode-driver-3232.html)

  Note: cables compatible with the LLH or HHL housing can be provided by ALPES LASERS.

- KEITHLEY Model 2420 High-Current SourceMeter w/ Measurements up to 60V and 3A, 60W Power Output (http://www.keithley.com/products/dcac/currentvoltage/highcurrent/?mn=2420)

Powermeter To measure the laser ouptput power, semiconductor powermeters such as those from OPHIR can be used (www.ophiropt.com).

Spectrometer Low resolution measurements measurements can be done with monochromators such as a TRIAX320 from JOBIN YVON (http://www.jobinyvon.com), special measurements (high resolution and CW) with a spectrometer such as the NICOLET 800 and 860 FTIR (www.nicolet.com), or BRUKER INSTRUMENTS (www.bruker.com).

Fast detectors For time-critical measurements, detectors from VIGO SYSTEM SA (www.vigo.com.pl).

Monitoring For monitoring laser emission, simple pyroelectric detectors can be used, such as the LGTP101 by MEMTEK (memtek.lgcit.com).

Beam collimation Due to the large divergence of the beam, it is recommended to use fast optics (f/1 . . . f/0.8) to collect most of the emitted light, like lens system aspheres from JANOS (http://www.janostech.com) or Optical solutions (http://www.opticalsolutionsinc.com).

1.5. Fields of applications

1.5.1. IR

The ALPES LASERS QCLs address the need for gas sensing and spectroscopy applications in the wavelength region from 3 to 15μm as most chemical compounds have their fundamental vibrational modes in the mid-infrared. More specifically, the high transparency of the atmosphere in two so-called atmospheric windows at approximately 3-5μm and 8-12μm allows remote sensing and detection. The long wavelength reduces Rayleigh scattering from dust and rain drops dramatically, allowing applications such as radars, ranging, anti-collision systems, covert telecommunications, etc. As an example, Rayleigh scattering decreases by a factor 10^4 for wavelengths ranging from 1μm to 10μm. Examples of applications are:

- Industrial process monitoring: contamination in semiconductor fabrication lines, food processing, brewering, combustion diagnostics. Life sciences and medical applications
- Medical diagnostics, biological contaminants.
- Law enforcement

  Drug or explosive detection.
- Military: chemical/biological agents detection, counter measures, covert telecommunications.

1.5.2. THz

Terahertz radiation is safe and non-ionizing. It bridges the gap between the mid-infrared and microwaves. It can penetrate most non-conductive materials and can be used in a wide range of applications:

- Water content mapping
- Tissue density mapping
- Metals detection
- Spectral identification

Terahertz QCLs operate in the range from 1 to 6 THz. Coherent polarized THz radiation is generated by means of direct stimulated optical transitions of electrons within the conduction band of a semiconductor heterostructure. THz lasers need cryogenic cooling but at temperatures higher than 77K (boiling point of liquid nitrogen), making their operation non-prohibitive in terms of cooling equipment.

ALPES LASERS THz QCLs are available as CoC or readily mounted in a variable temperature cryostat. ALPES LASERS offers three types of cryogenic system solutions:

- LN_2 dewar
- cryostat
- standalone

Contact ALPES LASERS for more details.

Note: THz QCLs are not pre-tested; contact ALPES LASERS to discuss the requirements for a specific application.

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2. Safety

ALPES LASERS electronic equipment operates with high voltage and includes a LASER that may cause serious injury if not handled properly. The guidelines in this document follow as closely as possible the IEC 60825-1 International Standard for safety of laser products.

> IMPORTANT:
> This document provides general safety instructions. Site specific safety regulations on electricity and lasers must be followed if they supersede the recommendations in this manual.

Potential sources of hazard when working with the Starter Kit are environmental, electrical or due to LASER radiation; they are explained in more detail in sections 2.3.1, 2.3.2 and 2.3.3. The access to potentially dangerous operations is not controlled and is left to the supervision of the owner.

> IMPORTANT:
> Any personnel working directly or in the surroundings of ALPES LASERS equipment must read carefully and understand the safety issues discussed in this chapter.

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2.1. General safety considerations

If any of the following conditions exist, or are even suspected, do not use the instrument until safe operation can be verified by trained service personnel:

- Visible damage
- Severe transport stress
- Prolonged storage under adverse conditions
- Failure to perform intended measurements or functions

If necessary, return the instrument to ALPES LASERS for service or repair to ensure that safety features are maintained.

2.2. Notation

The use of DANGER, WARNING and CAUTION notation in this manual is conform to the SEMI standard S-13-0298[1]; their definition is given below. They may also be used to alert against unsafe practices.

DANGER:
Indicates an **immediate** hazardous situation, which, if not avoided, may result in death or serious injury.

WARNING:
Indicates a **potentially** hazardous situation, which, if not avoided, may result in death or serious injury.

CAUTION:
Indicates a potentially hazardous situation, which, if not avoided, may result in minor or moderate injury or property damage.

The use of IMPORTANT and *Note* notations is defined below.

IMPORTANT:
Contains instructions or practices associated with maintenance and operation of the Starter Kit. Highlights specific actions or steps to be followed in order to avoid defeating equipment functionality or cause product damage.

Note: contains instructions or practices associated with maintaining the Starter Kit. Clarifies issues needing the reader's attention.

[1] SEMI S13-0298: *Safety Guidelines for Operation and Maintenance Manuals Used with Semiconductor Manufacturing Equipment*, Semiconductor Equipment and Materials International (Mountainview, CA) 1998

2.2.1. Symbols and labels

The danger and warning symbols used in this manual are shown in table 2.1.

	general danger		electrical hazard
	LASER radiation hazard		safety eyewear mandatory

Table 2.1.: Safety symbols most commonly used in the ALPES LASERS user's manual.

2.3. Health hazard

There are three main sources of hazard associated with the Starter Kit:

- LASER radiation, detailed in section 2.3.1;
- electrical, detailed in section 2.3.2;
- environmental, detailed in section 2.3.3.

2.3.1. LASER radiation hazard

The eye and skin are the body parts the most likely to be injured. Warnings for tasks that may lead to health hazard when operating a QCL are shown below.

WARNING:
Never insert shiny objects in the LASER beam path: stray reflections can be extremely hazardous to eyes and skin.

2.3.2. Electrical hazard

Work on live electrical circuits must be performed using all appropriate precautions and site specific procedures. Those tasks must be performed by qualified service personnel familiar with the wiring schematics of ALPES LASERS electronic equipment **only**; electrical cabinets shall *not* be accessed during normal operation nor during maintenance tasks.

DANGER:
Contact with the AC line can cause death or serious injury: ramp down power from all the equipment before attempting any maintenance procedure.

2.3.3. Environmental hazard

Always consult the material manufacturer's Material Safety Data Sheets (MSDS), paying close attention to dust and combustion by-products.

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3. Installation

This chapter presents the general workflow between delivery and operation of ALPES LASERS QCLs and electronic equipment:

IMPORTANT:
The facility must fulfill all prerequisites listed in section 3.1, all utilities must be duly prepared in a suitable location. The location of ALPES LASERS QCLs and electronic equipment must comply to the environmental conditions listed in section 3.1.1.

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3.1. Prerequisites

In this section are described the environmental conditions in which ALPES LASERS QCLs and electronic equipment should be stored and manipulated and prerequisites for its operation. The items listed in table 3.1 must be provided by the customer for ALPES LASERS QCLs and electronic equipment to be operated. It is highly advisable to have the *recommended equipment* available.

Prerequisites	
external power supply for LDD	stabilized DC power supply
	possibility of ramping the voltage up or down
	0 to 35 V
	up to 1A DC (minimum)
	ripple-free (less than 1%)
	current rating: laser operation current x duty cycle + 15%
CW laser driver	driver dedicated to CW lasers
	current control up to 4 A
	voltage rating up to 20 V
LLH water cooling (optional)	0.25 L/min at 10 to 20oC (tap water)
	4 mm flex cable
LDD (when not provided by AL)	pulse current of up to 10A
	voltage up to 12 V
	maximum rise/fall time of 10ns (to prevent detrimental heating)
tools	set of allen keys
	flat screwdriver
recommended equipment	oscilloscope
	powermeter (or other means of detector)
	multimeter

Table 3.1.: Prerequisites for the operation of the ALPES LASERS QCLs and Starter Kit.

3.1.1. Environmental conditions

The following guidelines are standard across all ALPES LASERS products:

- Indoor use only
- Ordinary Protection: This product is NOT protected against the harmful ingress of moisture.
- Maximum Relative Humidity: <80% RH, non-condensing
- Operating temperature range of 0°C to 40°C
- Storage and transportation temperature of -40°C to 70°C

Storage

All ALPES LASERS lasers are delivered in a hermetic waterproof storage box, shown in figure 3.1, in which the laser chip is held with pins. This box should always be used when storing the laser out of its housing. The laser chip is soldered to the pads using In soldering, which melts at 120°C, therefore the storage temperature should not exceed 80°C.

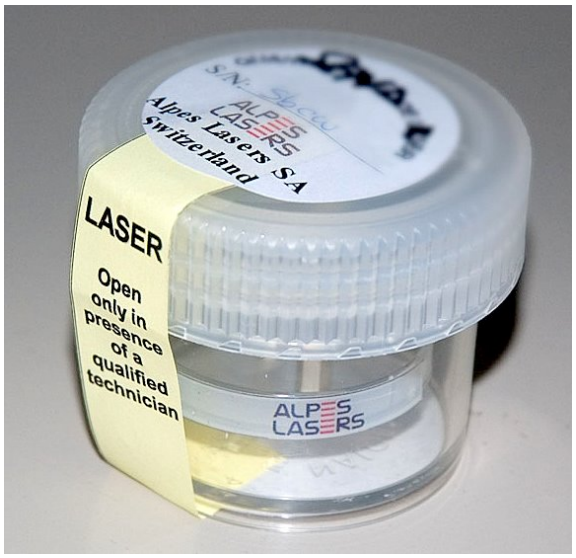

Figure 3.1.: ALPES LASERS QCL storage box.

QCLs can be stored at ambient temperature (10 to 30°C) in normal atmosphere. Humidity should not exceed 80%, and condensation is to be avoided. The laser must be operated in a dry atmosphere below 50% relative humidity. If possible, it should be completely dried using a desiccant material or by flushing with N_2.

CAUTION:
Even when packed, ALPES LASERS equipment should not be exposed to rain, snow or direct sunlight. Extreme temperature changes must be avoided.

3.1.2. Cooling

The laser performance is highly dependent on its operating temperature, it is therefore necessary to cool down the laser accordingly. The following setups can be used:

- for LLH only: closed loop cooling system with chiller
- for LLH only: tap water, Swagelok fitting to the tap, 4 mm tubing
- good mechanical contact between the LLH or HHL housing or QCL submount and the heat sink, such as an optical table
- heat sink and fan

CAUTION:
Overheating the laser chip may result in permanent damage.

3.2. Receiving procedure

Upon delivery of the Starter Kit, the following procedure must be performed:

1. check that all components are included in the shipment. By default, the QCL is included in its housing[1]; the remainder consists of different sets of components depending on the housing and operation mode of the laser. The default packing lists are given in table 3.2.

	LLH		HHL	
	pulsed	CW	pulsed	CW
TCU	x	x	x	x
LDD	x		x	
TPG	x		x	
power cords	x	x	x	x
CTL	x	x		
CTLm			x	x
CPL	x		x	
CIL		x		x

Figure 3.2.: Packing lists.

> IMPORTANT:
> The customer must control the incoming deliveries and inform ALPES LASERS about incomplete shipments or defective goods within 30 days after delivery.

2. before unpacking the Starter Kit components, make sure that all environmental conditions and prerequisites are fulfilled (see sections 3.1.1 and 3.1).

3. for LLH only: mount the laser submount into the LLH housing following the procedure presented in section 7.1.3.

4. check that the TCU voltage setting is appropriate: the fuse holder (6) on the rear panel shown in figure 3.3 should be set to 100-120V and 60 Hz for North America, 220-240 V and 50 Hz in Europe. If not, set the appropriate AC voltage by setting the fuse holder in the proper position:
   a) Pull out the fuse holder (3) from the socket (2)
   b) check that the fuse holder is in the proper position to get the appropriate voltage. The arrow on the fuse holder (3) should correspond to the mark on the socket (2).
   c) Insert the fuse holder (3) into the socket (2).

[1] Replacement lasers are delivered in their storage box.

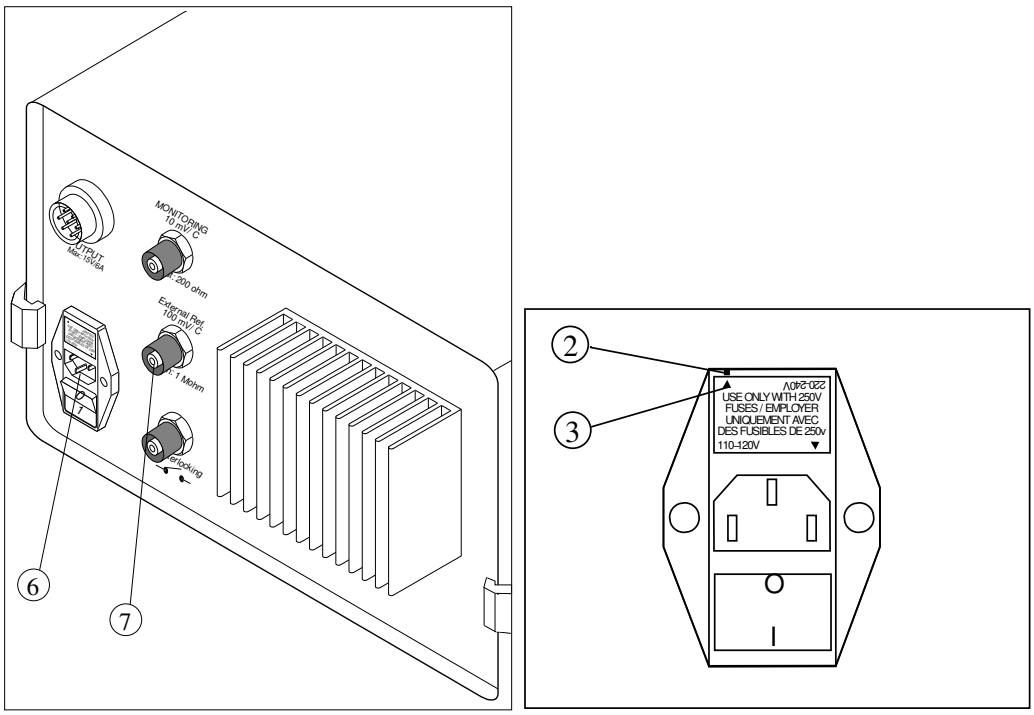

Figure 3.3.: TCU installation: rear panel (left), fuse holder (right).

3.3. Connections

Table 3.2 lists the cables and use of all connections for the Starter Kit including the LLH or HHL housing operated in pulsed or CW mode. Refer to figure 3.4 for cable identification.

from	to	cable	use	ref
TCU	LLH	CTL	temperature control and measurement	7
TCU	HHL	CTLm	temperature control and measurement	
TCU	mains	standard power cable	240 VAC power supply	
external power supply	mains	standard power cable	240 VAC power supply	
pulsed mode				
TPG	external power supply	CPL red/black banana cables	240 VAC power supply	8
external control circuit	LDD	CPL yellow/black banana cables	bias-T	8
TPG	LDD	CPL Lemo 00	12 VDC on center wire, power supply for LDD	1
TPG	LDD	BNC	timing signal	2
LDD	LLH	LBI	low impedance line for laser current control	
LDD	HHL	LBI via CTLm	low impedance line for laser current control	
CW mode				
ILX driver	LLH	CIL	current for laser control	
ILX driver	HHL	CIL via CTLm	power supply and low impedance line for laser current control	
ILX driver	mains	standard power cable	240 VAC power supply	

Table 3.2.: Starter Kit connections. The "ref" column refers to cable numbering in figure 3.4.

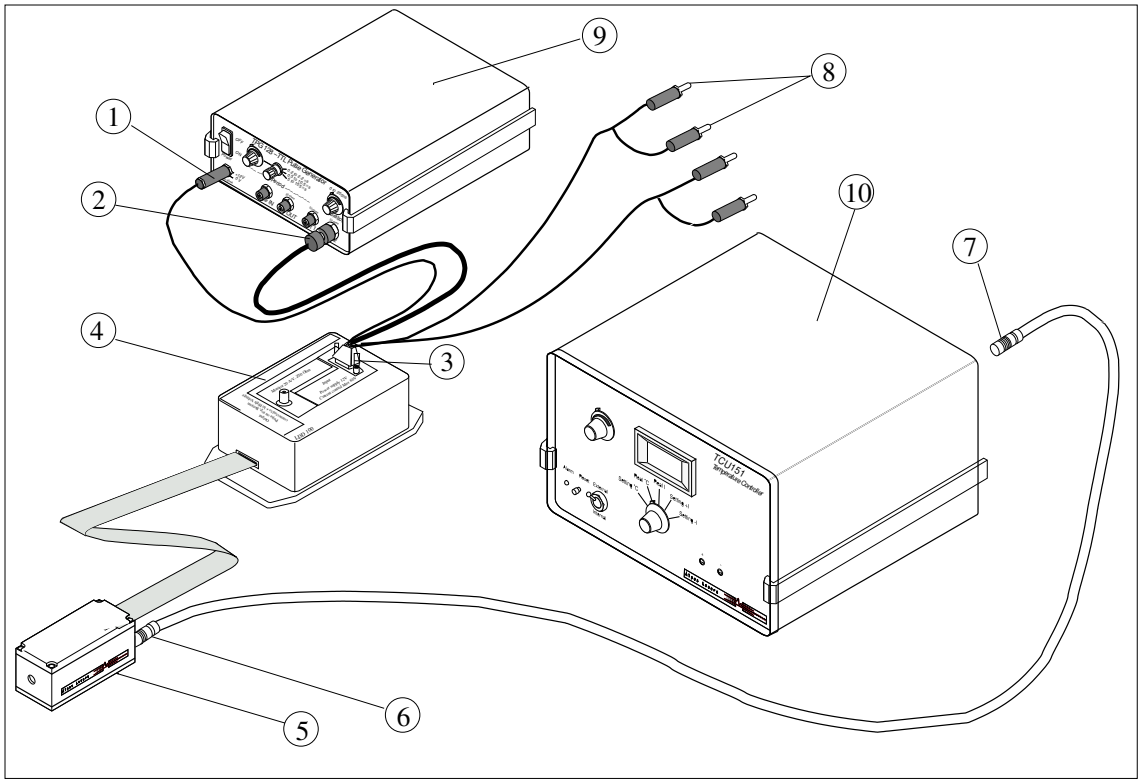

Figure 3.4.: Starter Kit cables.

3.3.1. LLH

The LLH front and rear panels shown in figure 3.5 consist of the following items:

- anti-reflective (3.5 to 12 μm) ZnSe coated laser beam window (1)
- CTL cable connector (2) for Peltier junction and PT-100 sensor
- connector for LBI or CIL cable (3)
- cooling water flow fittings (4) for 4 mm flexible cables
- monitoring *base* connector (5) and *laser* connector (6) for direct voltage measurement on the laser. The cables are not supplied by ALPES LASERS as it is a non-standard measurement.

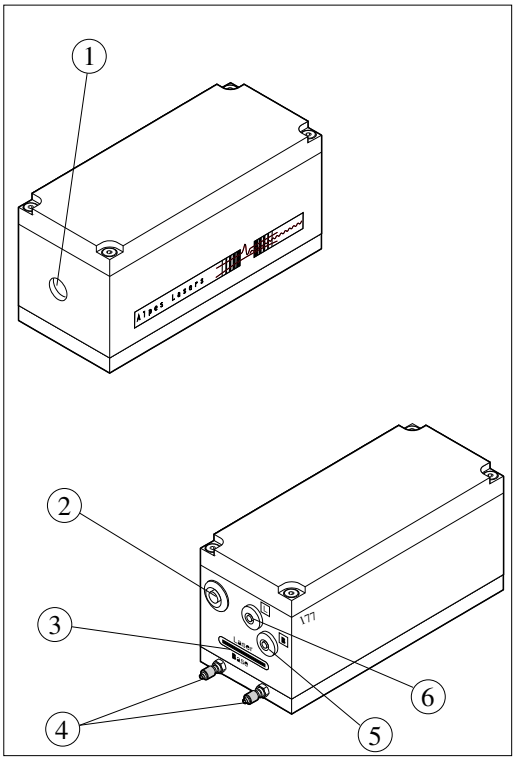

Figure 3.5.: LLH

IMPORTANT:
The low impedance line and laser chip are floating and connected to the *laser* connector and have negative polarity; the *base* connector must have positive polarity.

3.3.2. HHL

The HHL housing and CTLm cable shown in figure 3.6 must be connected according to the numbering of the CTLm connector pins (from 1 to 10) and the HHL connector pins description provided in section 3.3.6.

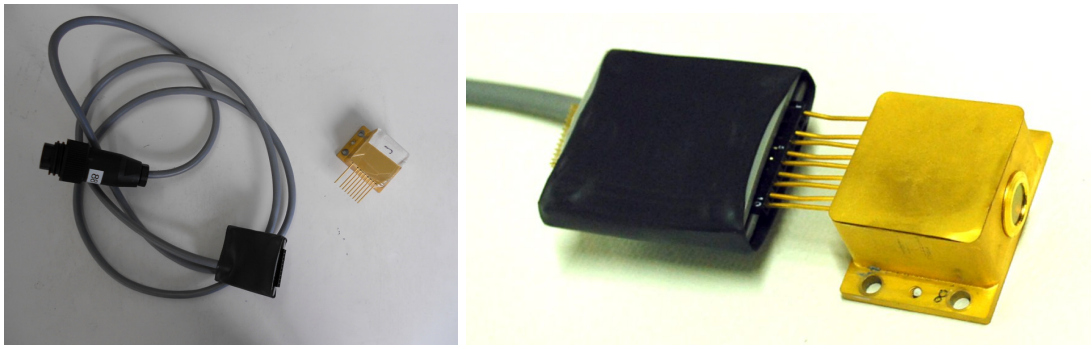

Figure 3.6.: HHL housing and CTLm cable.

3.3.3. TO3

Figure 3.7 shows the TO3 housing connector; the pinout is detailed in table 3.3. TO3-L and TO3-W housing have identical pinouts. The polarity of the laser connection is specified on the laser datasheet.

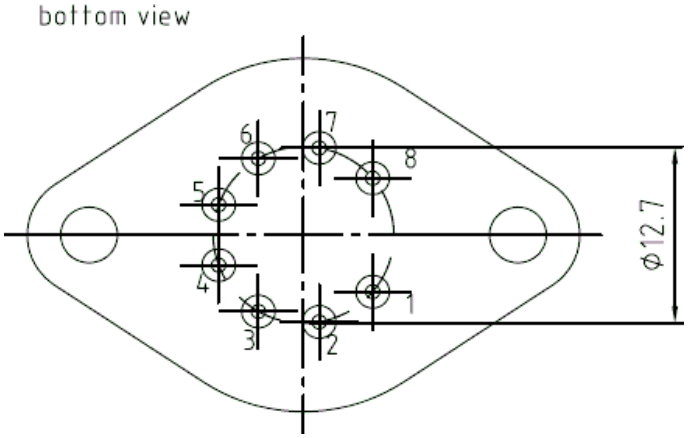

Figure 3.7.: TO3 housing connector.

Pin nb	Purpose
1	TEC +
2	Thermistor
3	Thermistor
4	laser bondpad
5	laser substrate
6	Not connected
7	Not connected
8	TEC -

Table 3.3.: TO3 housing pinout.

Note: ALPES LASERS does not produce cables for TO3 housings.

3.3.4. LDD

Figure 3.8 show the LDD connectors. The low-impedance line LBI has a locating pin to avoid false connection on the LLH laser housing and on LDD. The LBI has to be connected with "NEG" up unless specifically told to connect with "POS" up.

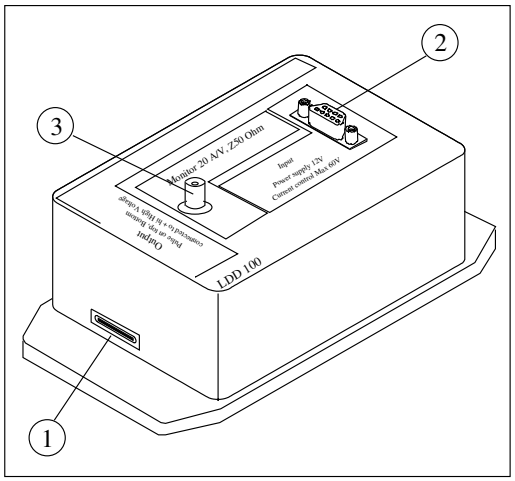

Figure 3.8.: LDD low impedance connector for LBI cable (1), drive cable connector for CPL cable (2) and monitoring BNC connector (3).

IMPORTANT:
The connection between the LDD and LLH or HHL must be floating and should not be grounded. Do not twist the LBI cable.

3.3.5. CTL cable

The TCU controls the temperature of the LLH with a Peltier junction and monitors the temperature with a PT100 through the CTL cable. The Peltier connector shown in figure 3.9 carries 6 pins, described in table 3.4. Pin 1 is circled, and a half-moon engraving runs from pin 1 to pin 6. A fixed current is supplied to pin 3 and 6. The resistance of the PT100 varies as a function of temperature and the temperature measurement is given by the voltage between pin 4 and 5.

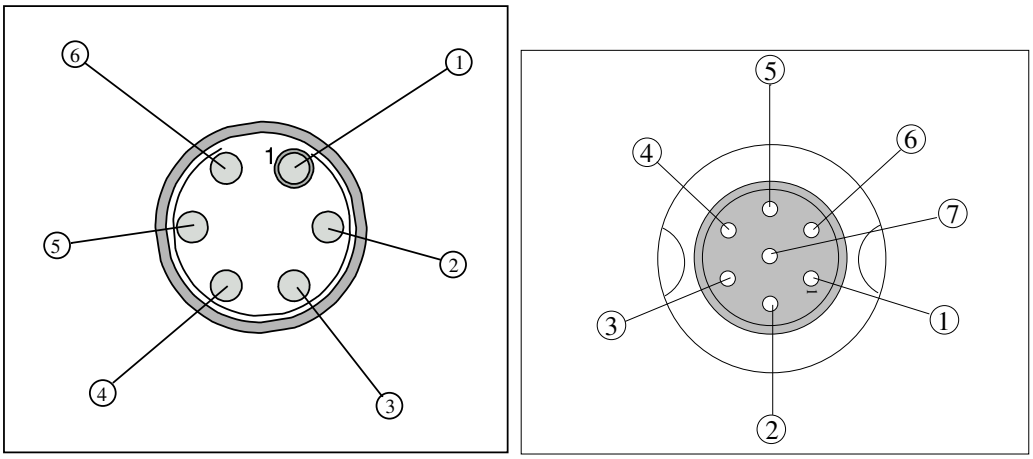

Figure 3.9.: Peltier junction and PT100 cable connectors on LLH (left) and TCU (right).

pin nb	name	purpose
1	1	+power supply for Peltier element
2	2	-power supply for Peltier element
3	3	+I PT100
4	4	+signal PT100
5	5	-signal PT100
6	6	-I PT100
7	GND	ground

Table 3.4.: CTL cable connector pinout.

3.3.6. CTLm cable

The CTLm cable connects the HHL on one side, and splits into two connectors on the other side: one for the TCU, the other for the laser driver. The TCU controls the temperature of the HHL with a Peltier junction and monitors the temperature with a PT100 temperature sensor. The TCU side of the CTLm cable is the same as the CTL cable, as described in section 3.3.5. The laser driver connector is compatible with the CIL cable for CW mode operation, or the LBI cable for pulsed mode operation. The HHL side of the CTLm cable contains the female connections described in table 3.5.

pin nb	**purpose**
1	-power supply for Peltier element
2	(no corresponding pin)
3	(not connected)
4	+power supply for laser
5	-signal PT100
6	+signal PT100
7	-power supply for laser
8	(not connected)
9	(not connected)
10	+power supply for Peltier element

Table 3.5.: CTLm cable HHL connector pinout.

The CTLm male connector for the laser driver has the same function as the LLH *laser* and *base* connector. It consists of two rows of pins; in one row, all pins are connected, and correspond to the *laser* connector (negative polarity), in the other row, two pins are removed, and correspond to the *base* connector (positive polarity).

3.3.7. CPL cable

The CPL cable shown in figure 3.10 connects the LDD to the TPG and external power supply, using a DE-9 connector on the LDD side, yellow/black banana connectors for Bias-T operation, Lemo 00 for LDD power supply, BNC for LDD timing signal and red/black banana connectors for TPG power supply

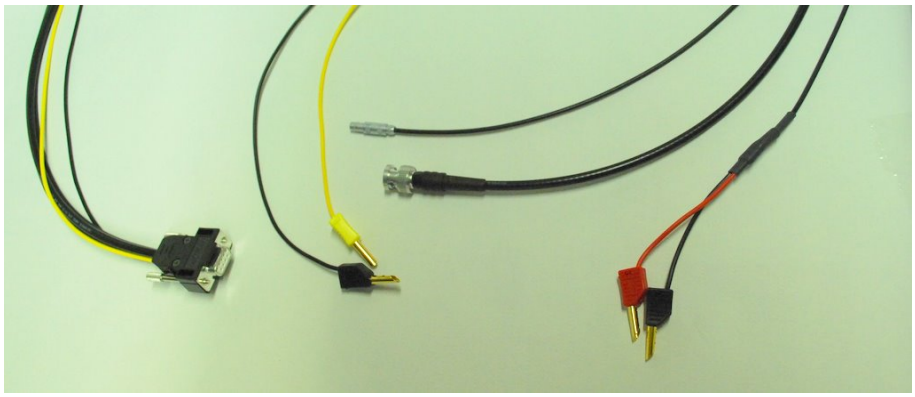

Figure 3.10.: CPL cable.

The LDD side consists of a D-sub-9 connector, composed of 9 pins as shown in figure 3.11 and described in table 3.6.

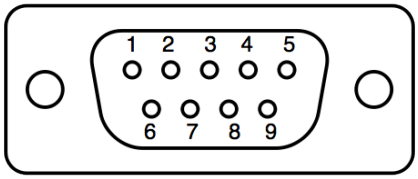

Figure 3.11.: DE-9 connector pinout numbering.

pin nb	purpose
1	+ external power supply (red banana cable)
2	center of LEMO connector (+12 V)
3	(not connected)
4	center of BNC connector
5	+ yellow banana cable
6	- external power supply (black banana cable, associated with red banana cable)
7	LEMO ground (chassis)
8	BNC ground (chassis)
9	- black banana cable (associated with yellow banana cable)

Table 3.6.: CPL cable connector pinout.

3.3.8. CIL cable

The CIL cable connects the LLH housing to the ILX LDX-3232 CW laser driver. On the LLH end, the connector consists of two rows of pin slots. All slots of one row are connected together, resulting in two terminals. In order to insure the correct polarity, some slots are filled with solder, which should match broken pins on the LLH connector.

The ILX side of the CIL cable consists of a D-sub-9 connector, shown in figure 3.11 and described in table 3.7.

pin nb	**purpose**
1	shorted with pin 2
2	shorted with pin 1
3	(not connected)
4	LLH connector (negative polarity)
5	LLH connector (negative polarity)
6	(not connected)
7	(not connected)
8	LLH connector (positive polarity)
9	LLH connector (positive polarity)

Table 3.7.: CIL cable connector pinout.

3.3.9. Connection procedure

The procedure to connect the Starter Kit components depends on the laser housing and operation mode. Refer to figure 3.4 for cable identification.

In all cases

To prevent any damage to the Starter Kit components, make sure the TPG, TCU and the external power supply are all turned off.

CAUTION:
Make sure that the connectors polarity is correct: the laser's ground must be floating for both its anode and cathode. Inverting the connector's polarity may result in permanent damage to the laser.

CW mode operation

- LLH housing in CW mode:
  1. connect the LLH to the TCU using the CTL cable
  2. connect the ILX to the LLH using the CIL cable
  3. if available, connect the cooling water tubing to the corresponding connectors of the LLH

     Note: if no water cooling is being used, carefully monitor the LLH module case temperature. Air cooling and heat dissipation must be provided.

CAUTION:
If the LLH module case exceeds a temperature of 60°C, permanent damage to the laser chip may occur.

- HHL housing in CW mode:
  1. connect the HHL to the TCU using the CTLm
  2. connect the ILX to the HHL using the CIL cable through the CTLm cable

Pulsed mode operation

1. connect the CPL cable to the LDD
2. connect the LDD to the TPG:
   a) using the CPL Lemo 00 +12VDC cable for power supply of the LDD
   b) using the CPL BNC cable into the *Out1* and *Out2* output

> IMPORTANT:
> The LDD ground must be floating.

3. connect the LDD to the external power supply using the CPL red and black banana cables
4. if no bias-T external circuit is to be used, shortcut the signal (yellow) and ground (black) banana cables by connecting them together. See section B.3 for details on bias-T control

- LLH housing in pulsed mode:
  1. connect the LLH to the TCU using the CTL cable
  2. connect the LLH to the LDD using the low impedance line LBI
  3. if available, connect the cooling water tubing to the corresponding connectors of the LLH

     Note: if no water cooling is being used, carefully monitor the LLH module case temperature. Air cooling and heat dissipation must be provided.

> CAUTION:
> If the LLH module case exceeds a temperature of 60°C, permanent damage to the laser chip may occur.

- HHL housing in pulsed mode:
  1. connect the HHL to the TCU using the CTLm
  2. connect the HHL to the LDD using the low impedance line LBI via the CTLm cable

4. QCL Operation

In this chapter, the general operation principle of a QCL is presented, and its main characteristics are illustrated using actual plots included in the datasheet provided with each ALPES LASERS QCL upon delivery.

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4.1. Principle of operation

Quantum Cascade Lasers (QCLs) are unipolar lasers emitting in the mid-infrared from 4 to 20 microns. The laser is a ridge of InGaAs and AlInAs grown on InP providing gain and a Fabry-Pérot cavity in order to build up the laser oscillations. ALPES LASERS produces QCLs of two types:

- Distributed Feedback (DFB) QCL: a grating is etched over the active region to force the operation of the laser at very specific wavelength given by the grating periodicity.
- Fabry-Pérot (FP) QCLs are capable of producing higher powers, but are typically multi-mode. They emit in a broad range of wavelengths and can cover more than 10% of the central emitting wavelength. FP QCLs are well suited for applications such as liquid spectroscopy and high power emitting sources, for which broadband emission is acceptable, and when no signal purity is required.
  - Broadgain QCLs consist in FP lasers designed for maximum width of the gain profile. They can be used as broad spectrum illuminators for spectroscopy or imaging. Combined with an anti-reflection coating, they are suitable for use in an external cavity to obtain a tunable laser with a wide tuning range.
  - THz FP QCLs can reach wavelengths of 70 to 200 μm but must be operated under cryogenic conditions; contact ALPES LASERS for more details.

4.2. ALPES LASERS datasheet

The datasheet provided with each ALPES LASERS QCL upon delivery contains the data obtained from standardized quality control tests performed at ALPES LASERS production site. The tests are performed on the QCL installed in a test-bench LLH housing operated at a temperature ranging from -30°C up to their maximal operating temperature (up to +50°C). If the QCL is then encapsulated in a different type of housing, the tests are repeated and a new datasheet is provided to the user. The measured parameters are used for controlling and comparing laser chips, performance evaluation and as starting points for operation parameters; they are readily available on ALPES LASERS website. Those parameters can be extrapolated for a specific application, or broader tests can be performed at ALPES LASERS on demand.

IMPORTANT:
The operating parameters are specified in the datasheet provided with each laser upon delivery; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.

In the following sections, examples of plots shown in the datasheets are presented, in order to help the user in operating ALPES LASERS QCLs in a safe and efficient manner.

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4.3. QCL spectra

A QCL is characterized by its emission frequency (spectral domain), wavelength or wavenumber (spatial domain); all three are equivalent. The following table gives typical values for ALPES LASERS QCLs.

wavelength (λ)	frequency (f)	wavenumber (ν)
4 - 20 μm 4000 - 20 000 nm	15 - 75 THz	500 - 2500 cm^{-1}

4.3.1. Temperature and current tuning

QCL emission can be precisely tuned with temperature (slow tuning) or current (quick tuning), but the later is in fact just apparent, as it results from the increase of temperature of the active region[1].

DFB QCL

Figure 4.1 shows the temperature and current tuning on a DFB laser operated in CW and pulsed modes. The wavelength increases (or the wavenumber decreases) by a factor varying between $7 \cdot 10^{-5}$ and $9 \cdot 10^{-5}$ for a temperature increase of 1 degree. For example, the total tuning for a 2000 cm^{-1} QCL operating over a range of -30 to +30°C will vary between 8.4 and 10.8 cm^{-1}, depending on the laser.

FP QCL

The spectrum of a FP laser of figure 4.2 shows an interference structure caused by the Fabry-Perot effect of the reflections at both ends of the laser chip, superimposed on a wide gain envelope. A temperature change will modify both these structures: the FP spectrum evolution is driven by the length of the laser cavity, which can vary, and the gain envelope evolves in unpredictable ways due to mode competition. The ALPES LASERS datasheet provides spectra taken at regular temperature intervals; additional requests on the spectral shape should be discussed with ALPES LASERS.

Figure 4.3 shows the spectrum of broadgain lasers.

[1] The temperature changes the apparent optical length of the grating, tuning the waveguide refraction index.

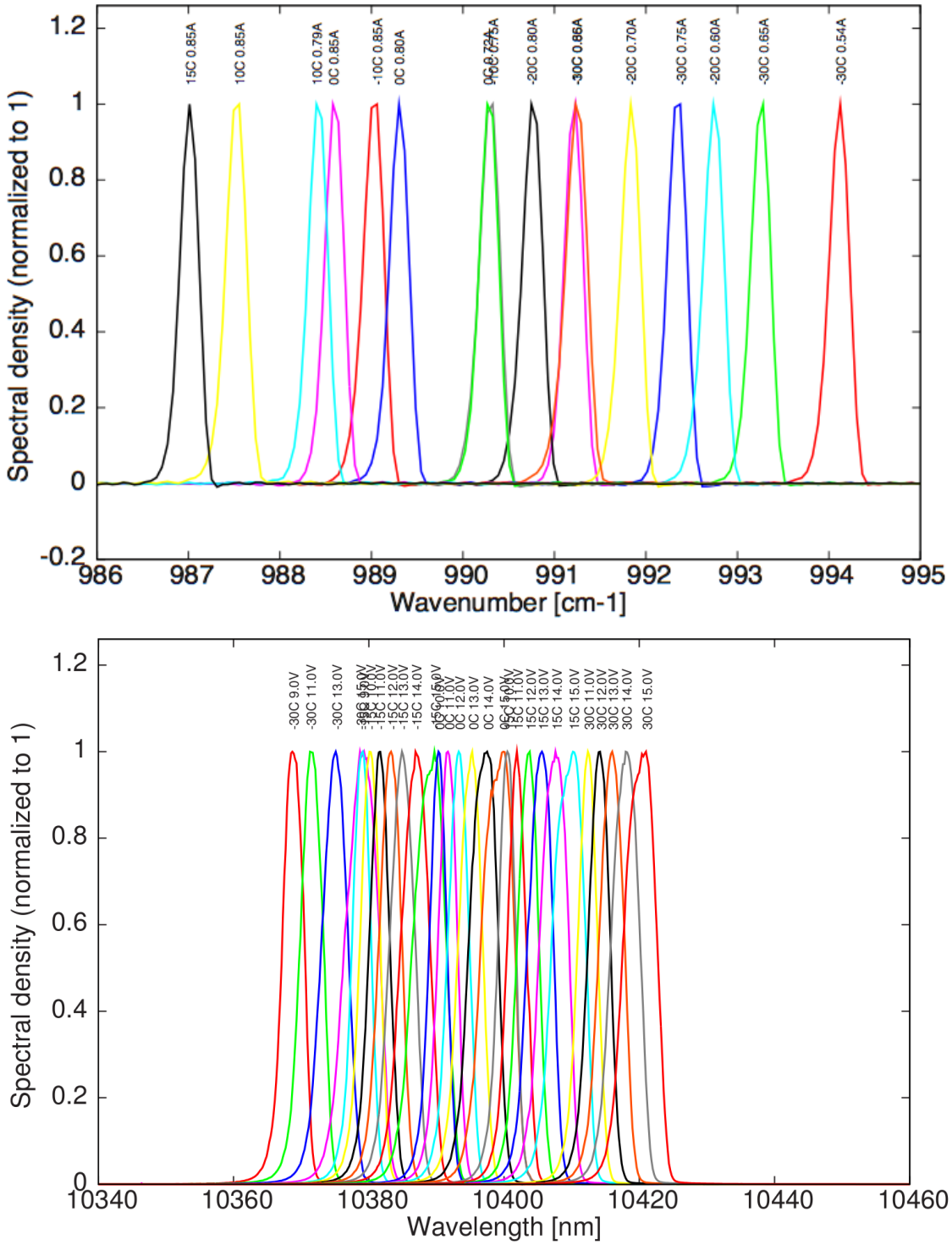

Figure 4.1.: Spectra of a DFB laser operated in CW mode (top) and pulsed mode (bottom) with different currents and temperatures.

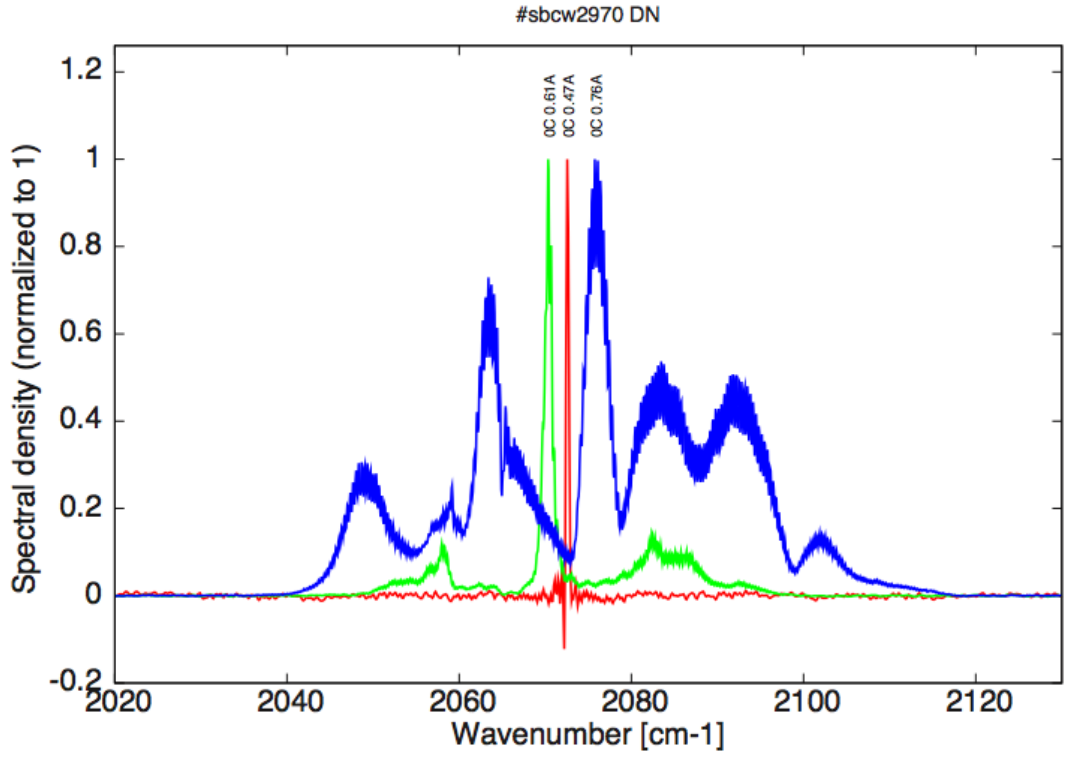

Figure 4.2.: Spectra of a FP laser operated in CW mode at fixed temperature and different currents.

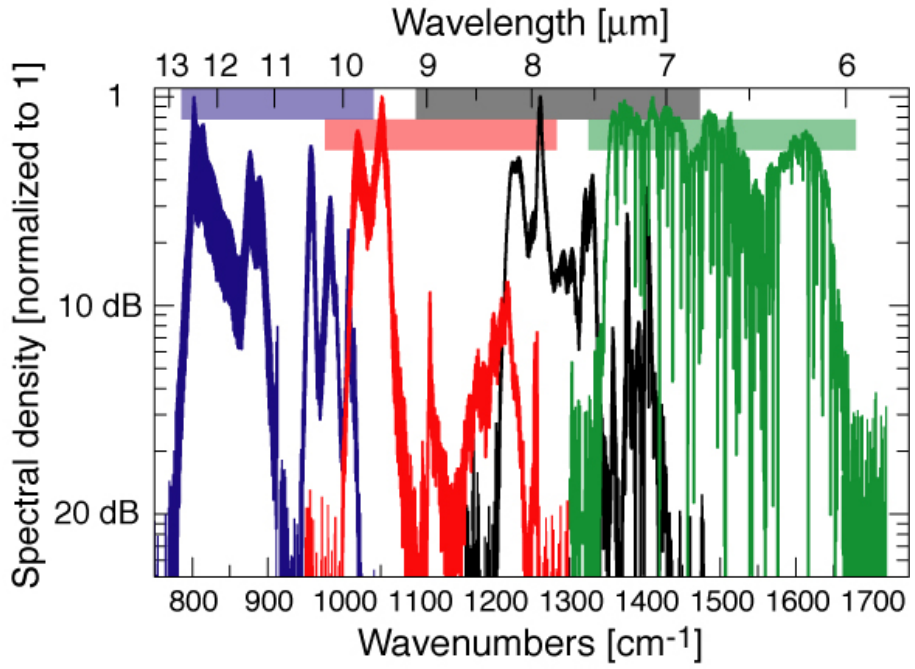

Figure 4.3.: Spectra of four different broadgain lasers.

4.3.2. Linewidth of pulsed single-mode DFB QCLs

The linewidth of DFB QCLs operated in pulsed mode depends on the pulse length, and is affected by chirping, which occurs because of thermal variations of the laser.

- Fine linewidth is obtained with short pulses (25 to 50 ns). ALPES LASERS QCLs are tested using pulse length of 25 to 50 ns, showing a linewidth < 0.2 cm^{-1}.
- Very fine linewidth (< 0.1 cm^{-1}) is obtained with pulses of 10 ns, which can be produced by dedicated equipment only.
- Longer pulses (> 50 ns) induce chirping, producing a broader linewidth when detected with a slow detector.

ALPES LASERS standard tests verify that DFB QCLs are singlemode, i.e. have a linewidth not exceeding 0.2 cm^{-1} with pulses of 50 ns.

Note: ALPES LASERS QCLs are characterized with a pulse length of 50 ns, but some QCLs may withstand pulse lengths up to 400 ns.

IMPORTANT:
The maximum pulse length an ALPES LASERS DFB QCL operated in pulsed mode can withstand is of typically 200 ns. Requirements for operation with pulses longer than 50 ns must be specified before purchasing a laser.

IMPORTANT:
The operating parameters are specified in the datasheet provided with each laser upon delivery; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.

4.3.3. Linewidth of CW single-mode DFB QCLs

DFB QCLs operated in CW mode reach thermal equilibrium with pulse length of 10 ms and longer. In this case, transient behavior affects only the beginning of the pulse, and can be neglected. The linewidth is therefore limited by thermal noise and electronic noise produced by the driver. Very long pulses (>100 ms) will behave in a CW manner, and shorter pulses will exhibit chirping as pulsed lasers do, and may induce multi-mode behavior.

IMPORTANT:
ALPES LASERS QCLs operated in CW mode are guaranteed to be single mode if operated with long pulses (> 10 ms) only.

4.3.4. Bandwidth of multi-mode FP QCLs

In the case of FP QCLs, the bandwidth is defined as the wavelength range in which 99% of the power is emitted. It depends on the driving current and is not affected by the operating temperature. ALPES LASERS QCLs operated in CW mode can withstand any pulse length.

4.4. I-V curve and emitted power

Figures 4.4 show the IV curves of DFB and FP lasers operated in CW at different temperatures. On the same graph the emitted power is plotted as a function of operation current, showing the current threshold for each temperature. For example, the DFB laser operated in CW mode (figure 4.4) has a threshold of 0.6 A at 20°C. It can be seen that cooling the QCL during operation enhances its performance as the threshold current decreases and output power increases.

CAUTION:
Do not operate the laser with a temperature and current above the values specified in the ALPES LASERS datasheet. Permanent damage may result.

Figure 4.5 can be used to illustrate the temperature and current tuning of a DFB QCL operated in pulsed mode:

- the power increases from 3 to 6 mW using a peak current of 4 A and varying the temperature from -30 to 30°C.
- for a temperature of 0°C, the power increases from 0 to 5.5 mW by increasing the peak current from 2 to 5 A.

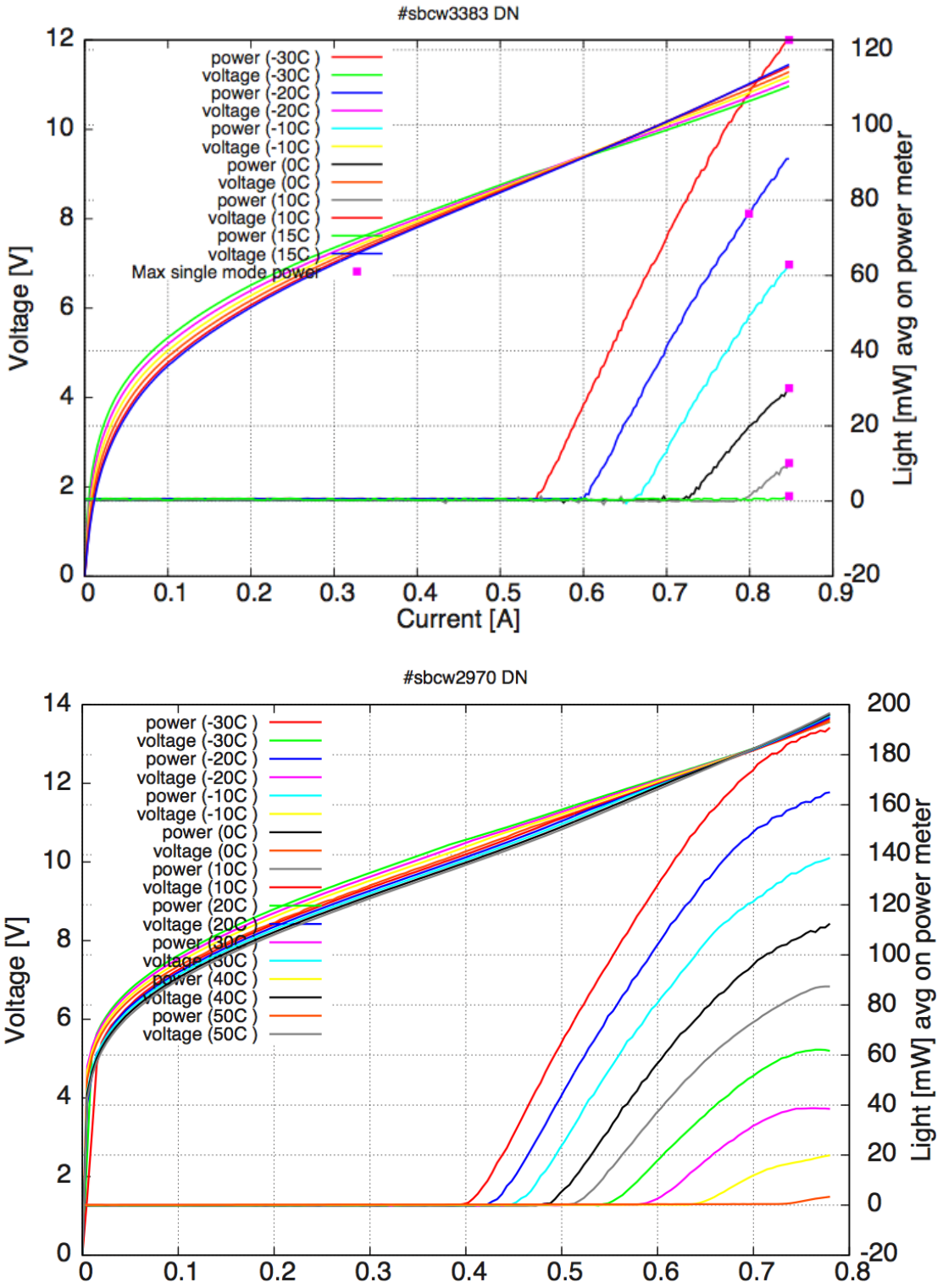

Figure 4.4.: IV curves of DFB laser (top) and FP laser (bottom) operated in CW mode at different temperatures.

4.4.1. Maximum operating current

All QCLs have a maximum operating current above which a Negative Differential Resistance (NDR) appears and may destroy the laser. As an example, figure 4.5 shows the IV curve and emitted power of a DFB QCL operated in pulsed mode: the green squares indicate the maximum current for monomode operation, 4.7 A from -30 to 30°C in the present case.

CAUTION:
The maximum operating current of each ALPES LASERS QCL is indicated in the IV and emitted power plots caption of the datasheet. Do not operate the laser with a current above those values; permanent damage may result.

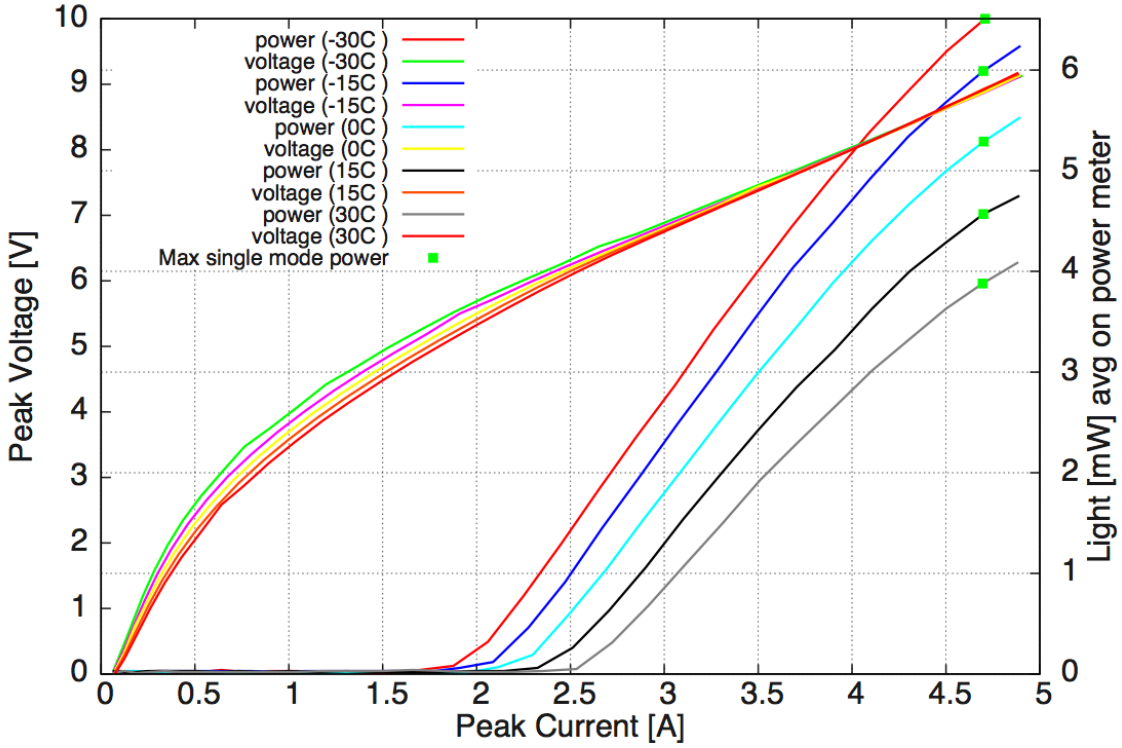

Figure 4.5.: IV curves of a DFB QCL operated in pulsed mode at different temperatures.

4.4.2. Maximum LDD voltage

Figure 4.6 shows the pulse peak current and emitted power as a function of the voltage fed to the LDD. In pulsed mode, the QCL operating current is controlled by the LDD, which is itself controlled by changing its operating voltage. The maximum LDD voltage is indicated by green squares on the emitted power curves; in this particular case, the voltage must not exceed 15 VDC.

CAUTION:
The maximum operating LDD voltage is indicated in the ALPES LASERS datasheet. Do not operate the LDD with a voltage above those values; permanent damage may result.

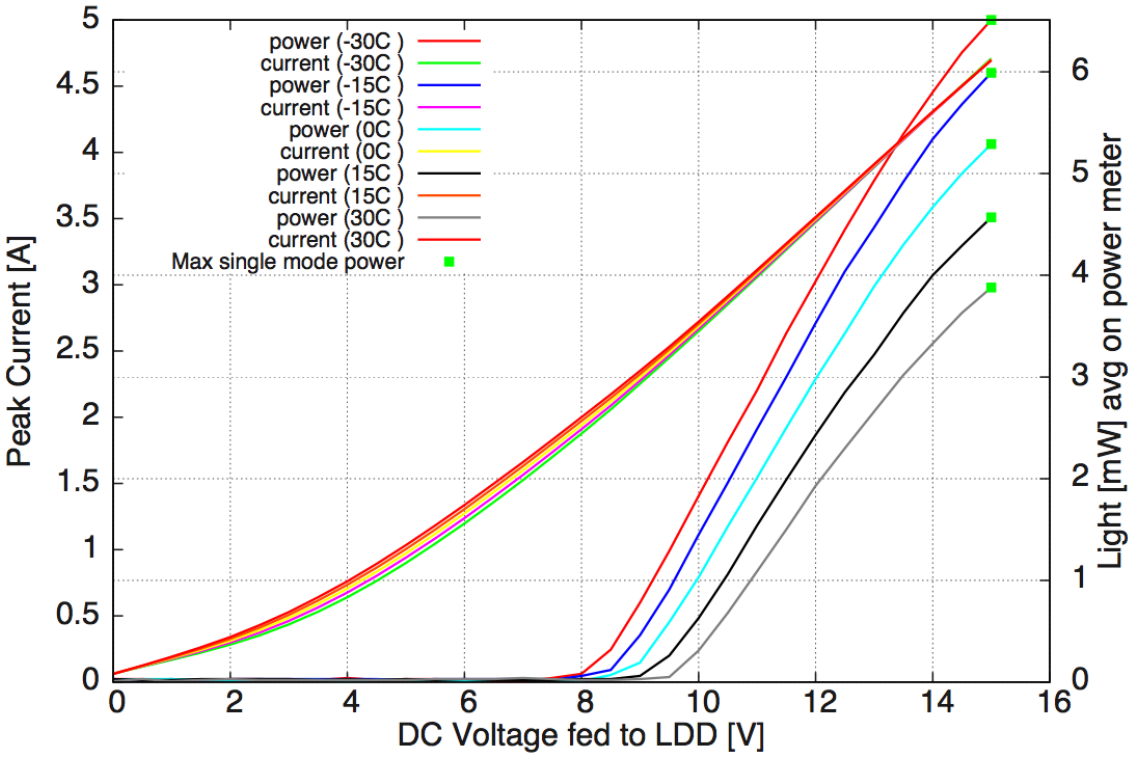

Figure 4.6.: Peak voltage and averaged emitted power as a function of LDD voltage of a DFB QCL operated in pulsed mode at different temperatures.

4.4.3. Other DFB QCL plots

The plots displayed in figure 4.7 show the emitted power and LDD voltage as a function of frequency, temperature and operating current. These curves help when setting up the operation parameters of a DFB QCL.

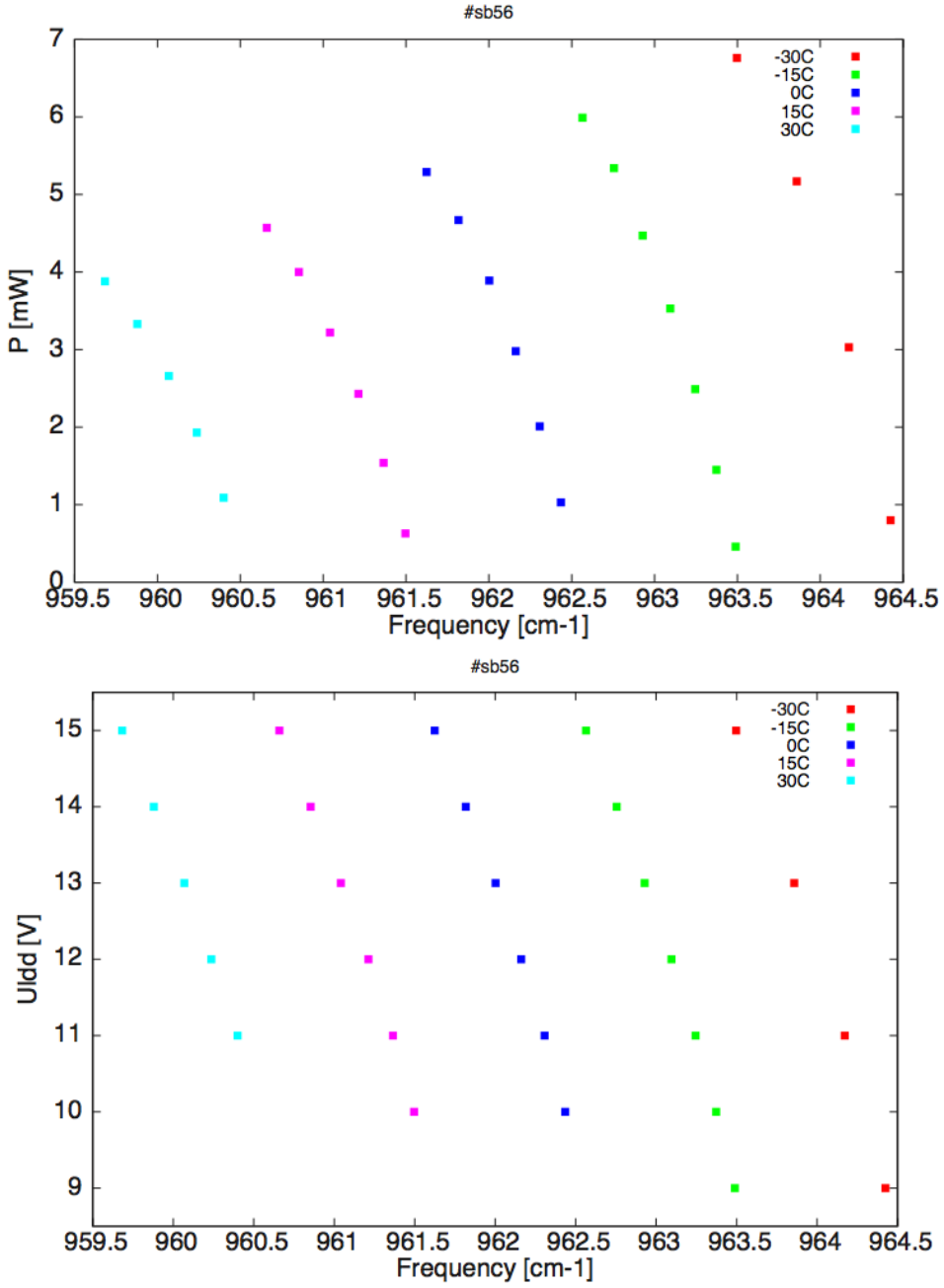

Figure 4.7.: Emitted power (top) and LDD voltage (bottom) as a function of frequency for a DFB laser operated in pulsed mode at different temperatures.

4.5. Beam Properties

Divergence

Figure 4.8 shows a typical ALPES LASERS QCL beam profile. Unipolar lasers consist in tightly confined waveguides; for this reason, the beam diffracts strongly at the output facet and has a full divergence angle of about 60 degrees perpendicular to the layer (vertical angle) and 40 degrees parallel to the layers (horizontal angle). A f/1 optics will typically collect about 70% of the emitted output power. Note that the collected output power will decrease with the square of the f-number of the collection optics.

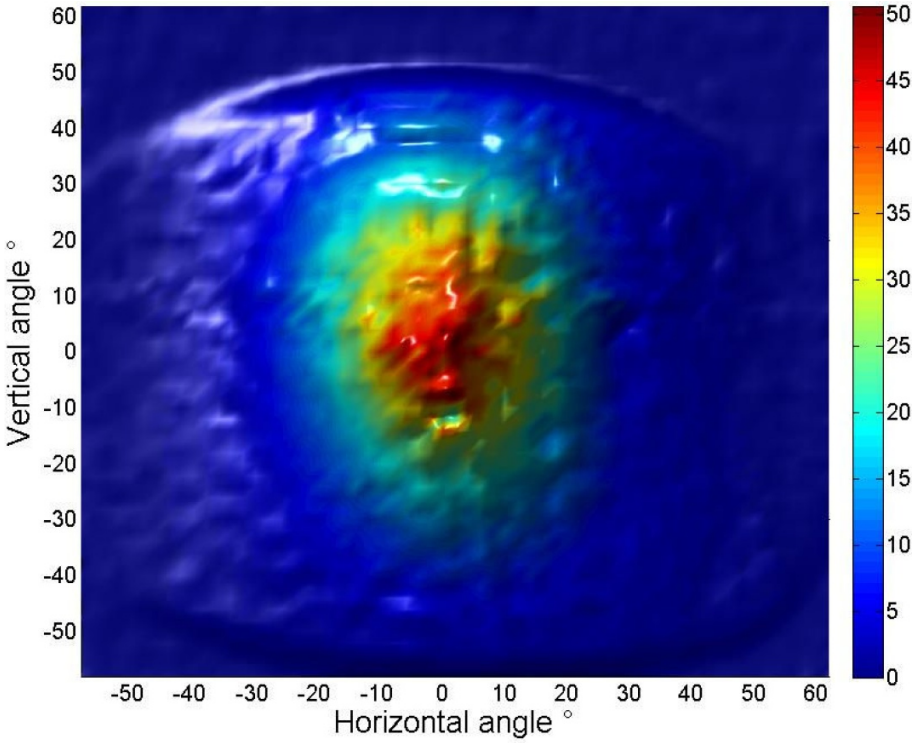

Figure 4.8.: QCL beam profile.

Polarization

Because the intersubband transition exhibits a quantum mechanical selection rule, the emission from a unipolar laser is always polarized linearly with the electric field perpendicular to the layers (and the copper submount).

Mode

ALPES LASERS QCLs are designed to have a single spatial mode, typically the Gaussian TEM00 mode. A mode measurement can be performed by ALPES LASERS on demand for a specific application.

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5. Starter Kit Operation

In this chapter are presented the operation instructions for the different components of the Starter Kit and the procedures to be followed for starting up and operating an ALPES LASERS laser.

> IMPORTANT:
> The operating parameters are listed in the datasheet provided with each laser; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.

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5.1. Temperature Controller Unit (TCU)

The TCU front and rear panels are shown in figure 5.1 and described below.

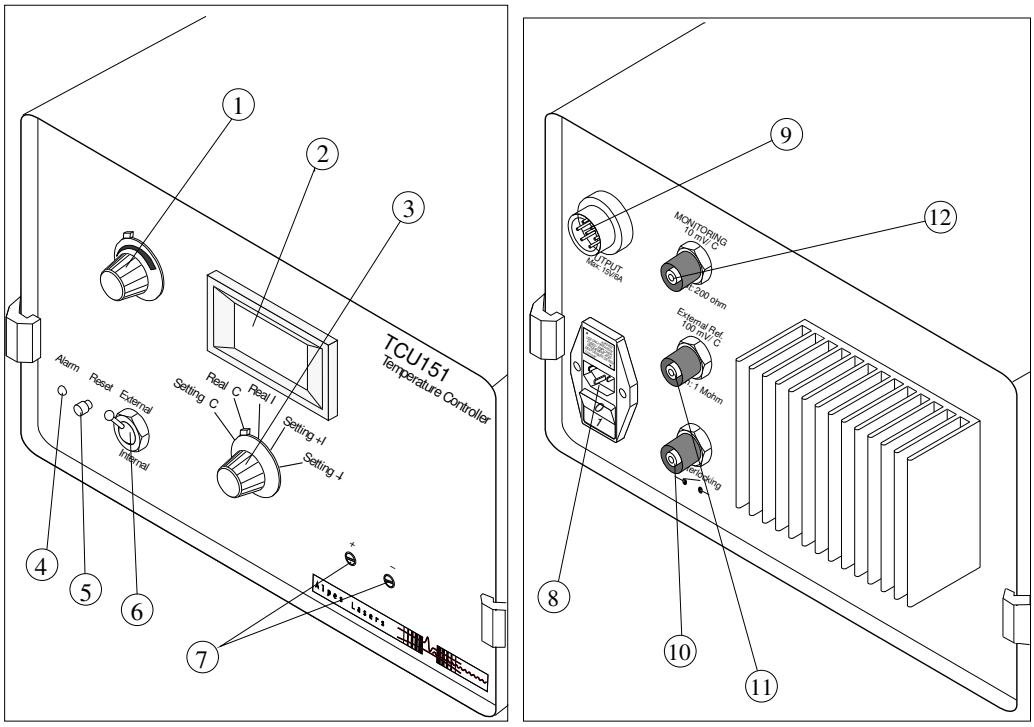

Figure 5.1.: TCU front (left) and rear (right) panels.

Command description

(1) Set Temperature 5 turns knob: Allows to set the internal temperature reference.

(2) LCD 3 digits display: Used to display either the actual sensor or reference temperature/current.

(3) Switch to select which temperature or current signals to display.

(4) Alarm display LED.

(5) Alarm reset switch.

(6) Toggle switch to select a function:

Set °C targeted temperature setting

Real °C actual temperature measurement in °C

Real I actual current in TEC given in A

Set +I highest current allowed

Set -I lowest current allowed

(7) Setting Current adjustment knobs. allow to modify the highest and lowest allowed currents, which are set in factory to 5A for the LLH and 2A for the HHL.

(8) Power ON/OFF fuse combined main switch.

(9) To LLH: AMPHENOL connector for LLH or LLH temperature control.

(10) Interlock BNC connector (see section 5.1.3).

(11) External reference BNC connector.

(12) Monitoring: BNC connector, see section 5.1.2 for details.

Note: the temperature setting and reading may have an offset of typically 0.1°C.

5.1.1. TCU startup

1. make sure the laser power supply is disconnected (see section 3.3 for connections)
2. turn on the TCU
3. set the desired temperature:
   a) select *Setting oC* using the switch (3) shown in figure 5.1 to display the desired temperature
   b) turn the knob (5) to set the temperature to the desired value
   c) select *Real oC* using the switch (3) to display the actual temperature
4. allow the laser temperature to reach the temperature setting

CAUTION:
Do not operate the laser at a temperature above the values specified in the ALPES LASERS datasheet. Permanent damage may result.

5. connect back the laser power supply

5.1.2. Internal/external mode

In *internal* mode, the temperature setting is performed using the temperature knob of the TCU front panel. In *external* mode, the temperature setting, monitoring and interlock are performed by an external control system using the BNC connections of the rear panel. In that case:

1. set the switch (5) to *external*
2. provide a $\pm$6.5V power supply to the *External Ref* BNC connector, using 100 mV/°C
3. read out the temperature through the *Monitoring* BNC connector, providing 10 mV/°C.

5.1.3. TCU interlock

The built-in TCU interlock is activated when a fault occurs on the TCU controller, e.g. prompt temperature rise. The interlock is by default an NC (Normally Close) relay contact, and may be reset by pressing the reset button (3) shown in figure 5.2.

Note: it is also possible to set the Interlock as a NO (Normally Open) contact.

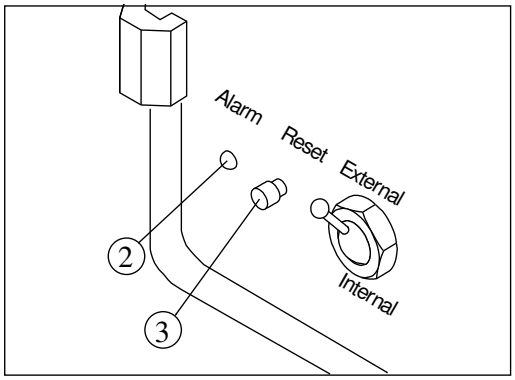

Figure 5.2.: TCU interlock.

Recovery procedure

This procedure must be followed in order to recover the temperature controller from an interlock event.

1. Turn off the QCL following procedure 5.3.2.
2. Identify the fault which activated the interlock and fix it.
3. Wait until the temperature is lower than the maximum allowed.
4. Press the RESET button (3) on the TCU rear panel (see figure 5.2).

The interlock is reset and the red LED alarm (2) should be off.

5.2. TTL Pulse Generator (TPG)

The front and rear panels of the TPG are shown in figure 1.11; a detailed view of the front panel is shown below in figure 5.3.

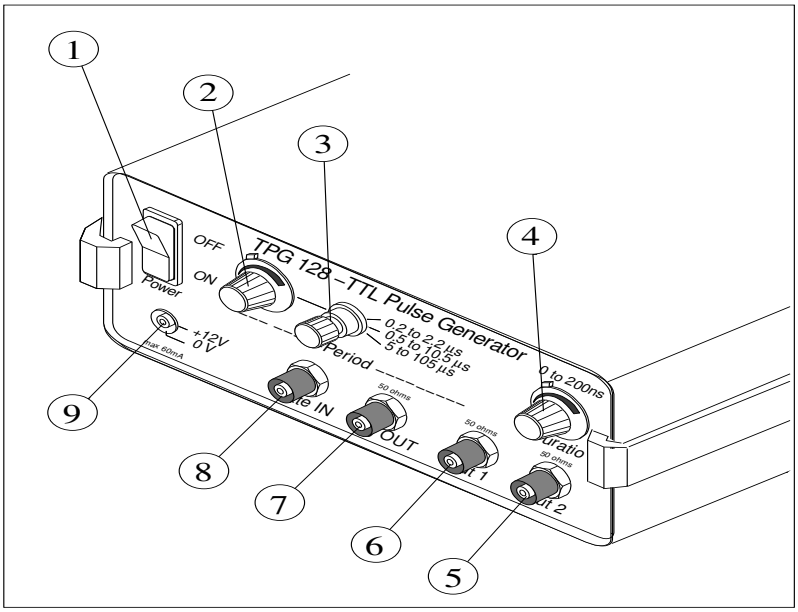

Figure 5.3.: TPG front panel.

Command description

The pulse duration can be set from 0 to 200ns and the interval between pulses from 200ns to 105 μs in 3 ranges, using the (2), (3) and (4) knobs shown in figure 5.3.

Note: the parameters should be adjusted using a scope following procedure 5.2.2.

(1) Power ON/OFF switch

(2) Pulse period fine potentiometer (10 turns)

(3) Pulse period range switch (3 positions)

(4) Pulse duration potentiometer (10 turns)

(5) BNC 50Ω TTL *Output*

(6) BNC 50Ω TTL *Trig OUT*

(7) BNC 50Ω TTL *Trig IN*

(8) BNC 50Ω TTL *Gate IN*

(9) CPL cable Lemo 00 12VDC output connector

5.2.1. Internal and external modes

The TPG can be operated in internal or external mode; the mode is selected with a switch on the rear panel of the TPG, as shown in figure 1.11. The input and output signals are provided or generated through the four BNC connectors shown in figure 5.3:

- in **internal mode**, a periodic signal is generated through the *Output* BNC connector. The *Trig OUT* BNC connector provides a 200 ns pulse for monitoring purpose or lock-in operation.
- in **external mode**, a signal is provided to the TPG through the *Gate IN* or *Trig IN* BNC connectors; in both cases the trigger precedes the output pulse by about 100ns.
  - the output generated with the *Gate IN* is a train of pulses corresponding to intANDext signals, as shown in figure 5.4.
  - the output generated with the *Trig IN* is a single pulse for a rising signal, as shown in figure 5.5.

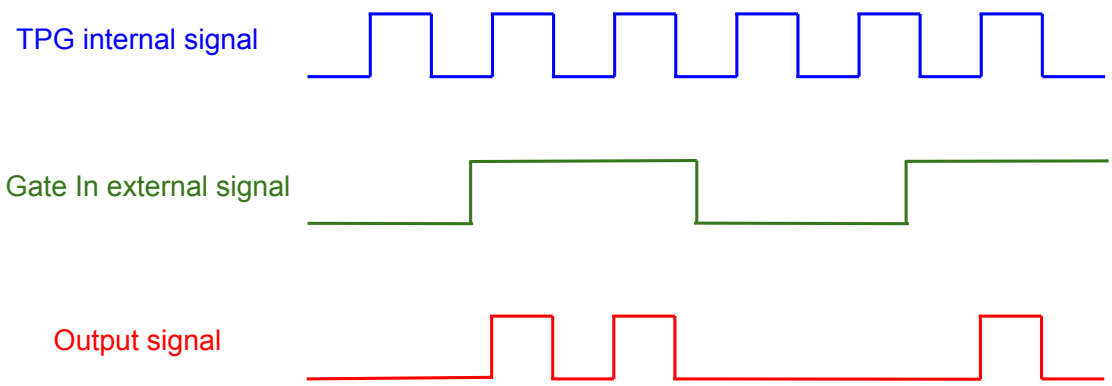

Figure 5.4.: TPG *Gate IN* external mode signal.

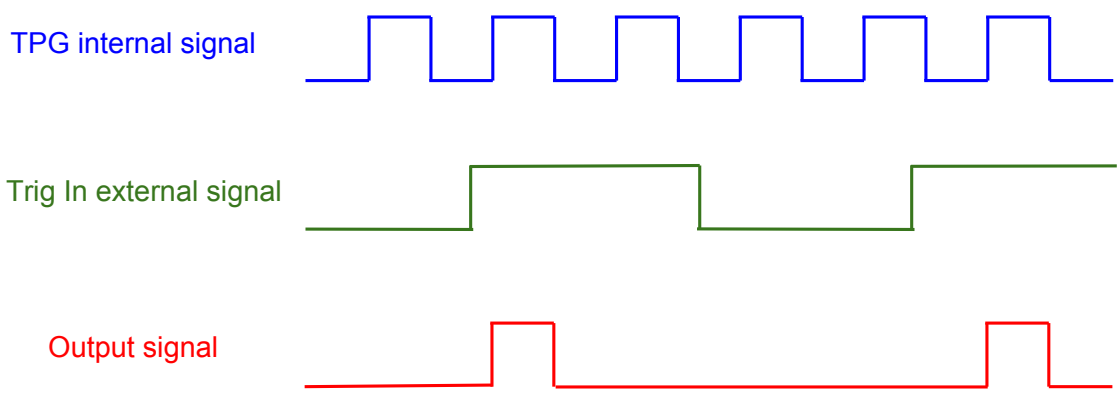

Figure 5.5.: TPG *Trig IN* external mode signal.

5.2.2. Setting the pulse parameters

1. remove the TPG from the Starter Kit and connect it to the mains independently
2. set the TPG mode to internal
3. connect the TPG to a scope using the *Output* BNC cable: a 5V TTL signal should be displayed
4. set the pulse parameters as specified in the datasheet (see section 4.2):
   a) set the pulse duration to 50 ns using the 0-200 ns knob (4)
   b) set the pulse period to 2.5 μs using the period knob (2) and toggle switch (3)
5. once the testing conditions are retrieved, set the pulse parameters as desired, but within a reasonable range of the parameters specified in the datasheet.
   Note: the pulse duration should be kept long enough to not distort the TTL signal.
6. lock the knobs (2) and (4)
7. turn off the TPG and disconnect it from the mains

IMPORTANT:
The operating parameters are specified in the datasheet provided with each laser; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.

5.2.3. Maximum duty cycle

The TPG is capable of operating with pulses as long as 200 ns; however for short periods (high duty cycle) the following limitations apply:

T=400ns: ..... t max = 200ns

T=300ns: ..... t max = 200ns

T=250ns: ..... t max = 150ns

T=200ns: ..... t max = 100ns

where T is the period and t_{max} is maximum pulse length.

CAUTION:
The laser shall only be operated under conditions as specified in the datasheet or by ALPES LASERS directly: all other operation may result in the destruction of the laser and loss of warranty.

While the TPG alone is capable of exceeding a duty cycle of 50% in some conditions, the maximum duty cycle of the pulser system is of 50%; a fuse protects the TPG from operating at larger cycles when under load. If larger cycles are needed, the LDD must be powered by an external 12V power supply. To operate a laser with a duty cycle higher than specified, it is mandatory to monitor its average output power and comply to the following guidelines:

- do *not* increase the duty cycle further when the power saturates, but rather reduce it.
- it is advisable to increase the duty cycle by reducing the pulse period, rather than increasing the pulse length, since the latter is more likely to damage the laser: increasing the pulse length increases the short time heat load on the laser, as reducing the pulse period increases the average heat load.
- the exact percentage of maximum duty cycle depends on the laser

5.3. General procedures

CAUTION:
The laser shall only be operated under conditions as specified in the datasheet or by ALPES LASERS directly: all other operation may result in the destruction of the laser and loss of warranty.

5.3.1. QCL startup

In order to insure the laser's performance and enhance its lifetime, the following steps must be followed thoroughly:

1. make sure all devices are turned off
2. start cooling for LLH or HHL housing (see section 3.1 for prerequisites)

CAUTION:
The laser must be used at the temperature specified in the datasheet. Operating the laser below or above the given temperature is likely to damage the laser and will result in the loss of warranty.

   Contact ALPES LASERS or a representant before using the laser at a temperature outside the range specified in the datasheet.

3. startup the TCU following procedure 5.1.1
4. if the laser is operated in CW mode, follow procedures included in the CW laser driver OEM manual. Always keep the current 1mA above 0 to avoid reversing the polarity.
5. if the laser is operated in pulsed mode:
   a) startup the external power supply:
      i. connect the external power supply to mains
      ii. remove the red/black banana cables
      iii. turn on the external power supply
      iv. set the voltage and current to 0, but keep the voltage 100 mV above 0 to avoid accidental polarity reversal
      v. turn off the external power supply

vi. connect the red/black banana cables

vii. switch on the external power supply

b) setup the TPG pulse parameters following the guidelines of section 5.2

c) connect the TPG back to the Starter Kit and turn it on

CAUTION:
Make sure the laser temperature is below specifications before turning on the external power supply. Overheating the laser chip may result in permanent damage.

6. increase the voltage slowly and monitor the current according to the QCL IV curve included in the ALPES LASERS datasheet (see section 4.4):
   - the current should start increasing at the threshold voltage, at a value close to the one indicated in the ALPES LASERS datasheet
   - for pulsed mode: at maximum voltage, the current supplied by the external power supply (eps) should correspond to the maximum peak current (see section 4.4.1) of the datasheet multiplied by the duty cycle with some overhead:

$$I_{\text{eps}} = I_{\text{peak}} \times \text{duty cycle} + \text{overhead}$$

CAUTION:
Do not exceed maximum voltage or current specified in ALPES LASERS datasheet. Permanent damage to the laser chip may occur.

   - if no current is flowing, a misconnection might be the cause, repeat step 8 of the installation procedure described in section 3.2
   - if a current above 100 mA is read, a ground loop might be the cause, review all connections according to section 3.3

7. monitor the laser power using a powermeter:

   a) make sure that the range suits the power range of the laser (see datasheet)

   b) reset it to 0

   c) align the laser beam with the powermeter

   The power should start rising around the threshold of the ALPES LASERS datasheet IV curve (see section 4.4).

   Note: exact power measurement of an IR beam is very difficult as it depends on ambient temperature and powermeter characteristics. Therefore the exact values shown in the datasheet might not be reproduced in a different setup as the one used by ALPES LASERS for routine tests.

5.3.2. QCL shutdown

1. reduce the external power supply voltage slowly, do *not* reach 0 as the polarity might reverse

CAUTION:
Make sure the polarity of the laser is correct. Permanent damage may occur.

2. if the QCL is operated in pulsed mode: turn off the TPG
3. set the TCU to a temperature close to ambient temperature
4. wait until the temperature setting is reached
5. turn off the TCU

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6. Technical specifications

The technical specifications of ALPES LASERS products are given in the following tables:

- QCLs in table 6.1
- housings in table 6.2
- electronic equipment in table 6.3
- Broadgain Lasers bandwidth in table 6.4

Some technicals drawings are provided in figures 6.5, 6.6, 6.7 and 6.8.

	Distributed Feedback	**Fabry-Perot**
Type	Single mode lasers	Multi mode lasers
Wavelength	4.2-14 microns	4.2-14 microns
Wavelength range	2-7 cm-1	50-300 cm-1
Power	0.5-300 milliwatt	0.5-300 milliwatt
Pulse length	25 ns to continuous	25 ns to continuous
Temperature of operation	77K to 323 K	77K to 323 K
Mounts	NS or ST or special	NS or ST or special

Figure 6.1.: Technical specifications of ALPES LASERS QCLs.

	Laser Laboratory Housing (LLH)	High Heat Load (HHL)	TO3	TO3W
Main purpose	Easy laser exchange	Sealed	with lens	with window
Size	100 mm X 50 mm X 50 mm	70 mm X 54 mm X 25.5 mm	38.8 mm X 25.4 mm X 20.5 mm	38.8 mm X 25.4 mm X 20.5 mm
Input	LBI connector, CTL connector, water connectors	Ten-Pin connector	8 pins connector	8 pins connector
Output port	Anti-reflection coated ZnSe protective window	Anti-reflection coated ZnSe protective window	Anti-reflection coated ZnSe collimating lens	Anti-reflection coated ZnSe window
Output beam	Divergent beam	Collimated, divergence < 6 mrad, 4 mm beam diameter	Collimated beam, divergence < 10 mrad, 4 mm beam diameter	Divergent beam 40° X 60° FWHM
Thermoelectric cooler	Peltier cooled laser-stage inside, minimal temperature -30°C	Peltier cooled laser-stage inside, minimal temperature -20°C	Peltier cooled laser-stage inside, max. dissipation 4W	Peltier cooled laser-stage inside, max. dissipation 4W
Temperature monitoring	Pt100	Pt100 or NTC temperature measurement.	NTC thermistor	NTC thermistor
Max TEC current	5.0 A	3.0 A (2.5A on some items)	3.0A	3.0A
Max TEC voltage	17 V	11.6 V (11.0 V on some items)	2.85V	2.85V
Laser Capacity	Supports all NS-mounted CW and pulsed lasers from Alpes Lasers	Supports CW or pulsed lasers with dissipation < 6 W on NS mount	Supports pulsed lasers with <4W average dissipation	Supports pulsed lasers with <4W average dissipation
Cooling needs	The backplate is equipped with a water cooling circuit and connections suitable for 4mm flexible pipes. Water cooling is only necessary for operation temperatures <0°C.	The backplate must be kept at room temperature, up to 35W of heat dissipation needed.	The backplate must be kept at room temperature, up to 10W of heat dissipation needed.	The backplate must be kept at room temperature, up to 10W of heat dissipation needed.

Figure 6.2.: Technical specifications of ALPES LASERS QCL housings.

	Laser Diode Driver (LDD)
Size	15cm X 6cm X 9 cm
Input	Power and timing input provided by CTL cable and associated equipment - see manual
Output	High current pulses through low impedance cable
Peak Current output	0-15 A
Voltage compliance	50V
Rise/fall time	10 ns
Pulse duration	>10ns (with attenuation), flat from 20ns to DC
Repetition Rate	Up to 4 MHz
Duty Cycle	<90%
Operation Temperature	0°C to 60°C

	TTL Pulse Generator (TPG)
Size	23cm X 13.7cm X 6.8cm
Power Input	Mains power (120/240V, 50/60Hz)
Power Output	12V on Lemo connector
Timing input	Optional TTL Gate in/Trig in
Timing Output	TTL signal on BNC connector
Max Current	150 mA
Pulse duration	22 ns - 200 ns
Interval between pulses	100 ns - 105 us
Duty Cycle	up to 50%
Operation Temperature	-60°C to +60°C

	Temperature Control Unit (TCU)
Size	11.5cm x 22cm x 27.5cm
Power Input	Mains power (120/240V, 50/60Hz)
Input/Output	Through supplied CTL cable
Internal Control	Front panel buttons
External Control	Temperature setpoint can be controlled by voltage on a BNC connector: 10°C/V from -6.5V to +6.5V
Max Current	5.0 A
Temperature setpoint range	-65°C-+65°C
Temperature sensor	pt100

	CW current driver
Manufacturer	ILX Lightwave
Size	31.5 cm X 21.5 cm X 8.5 cm
Power Input	Mains power (120/240V, 50/60Hz)
Power Output	D-Sub-9 connector and CIL cable
Max Current	4.0 A
Compliance Voltage	15 V
External Modulation	DC-250 kHz through 400mA/V input
Duty Cycle	up to 50%

Figure 6.3.: Technical specifications of ALPES LASERS electronic equipment.

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Type	FP min	FP max	PEC-min	PEC-max	CWEC-min	CWEC-max
BG-10-12	780	1030	787	1042	-	-
BG-8-10	995	1260	976	1283	1020	1235
BG-7-8	1190	1425	1096	1473	1150	1420
BG-6-7	1345	1660	1325	1680	1370	1635

Figure 6.4.: Examples of broadgain laser parameters, , where *FP min and max* are the limits of the multimode emission, *PEC min and max* are the observed limits of single mode pulsed emission in an external cavity and *CWEC min and max* the observed limits of continuous emission in an external cavity. Parameters were measured without AR coatings. Note that performance may vary depending on the external cavity.

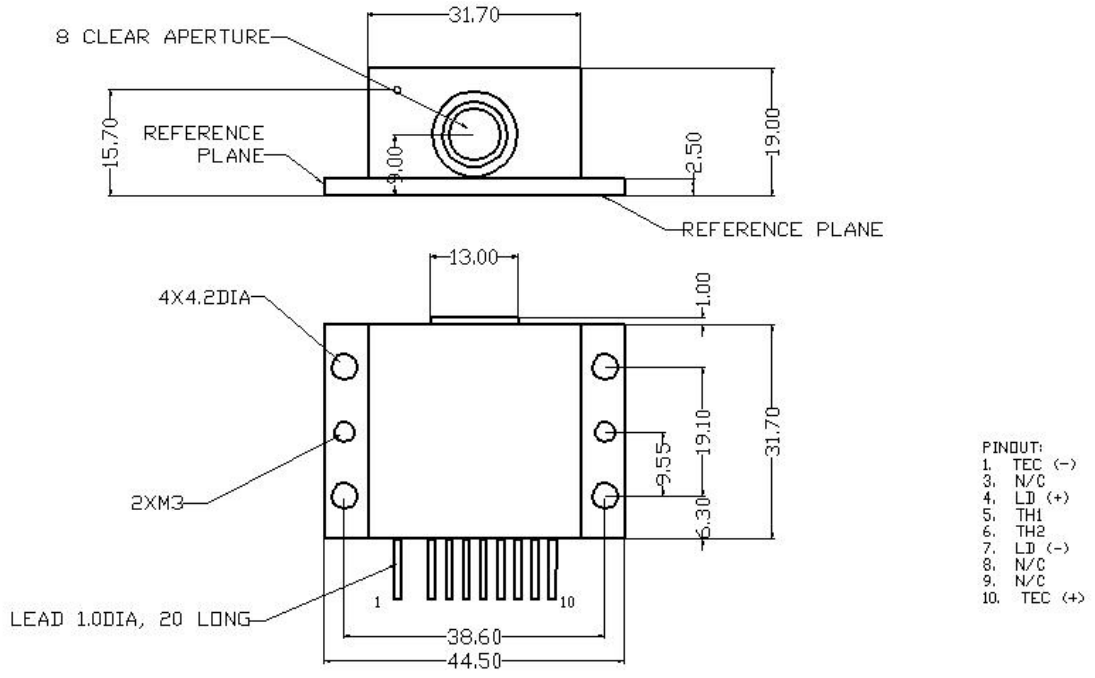

Figure 6.5.: HHL housing.

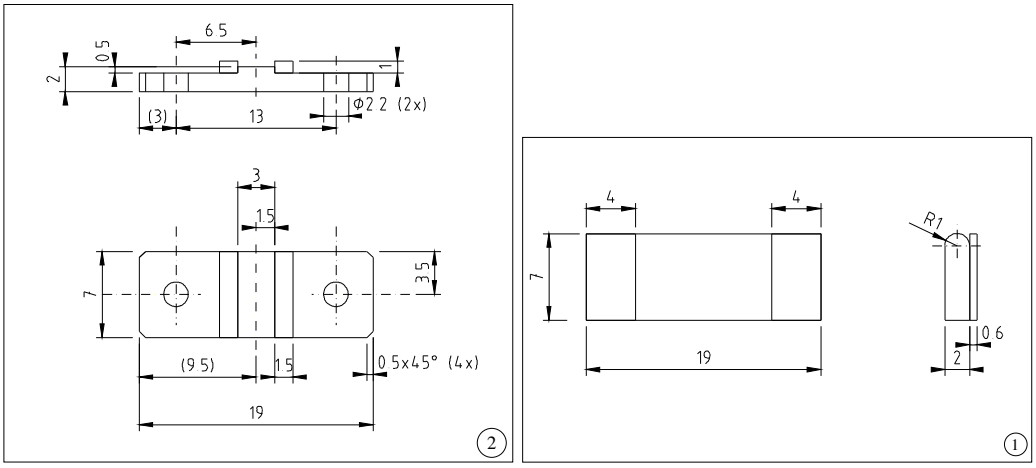

Figure 6.6.: NS (left) and ST (right) mounting support.

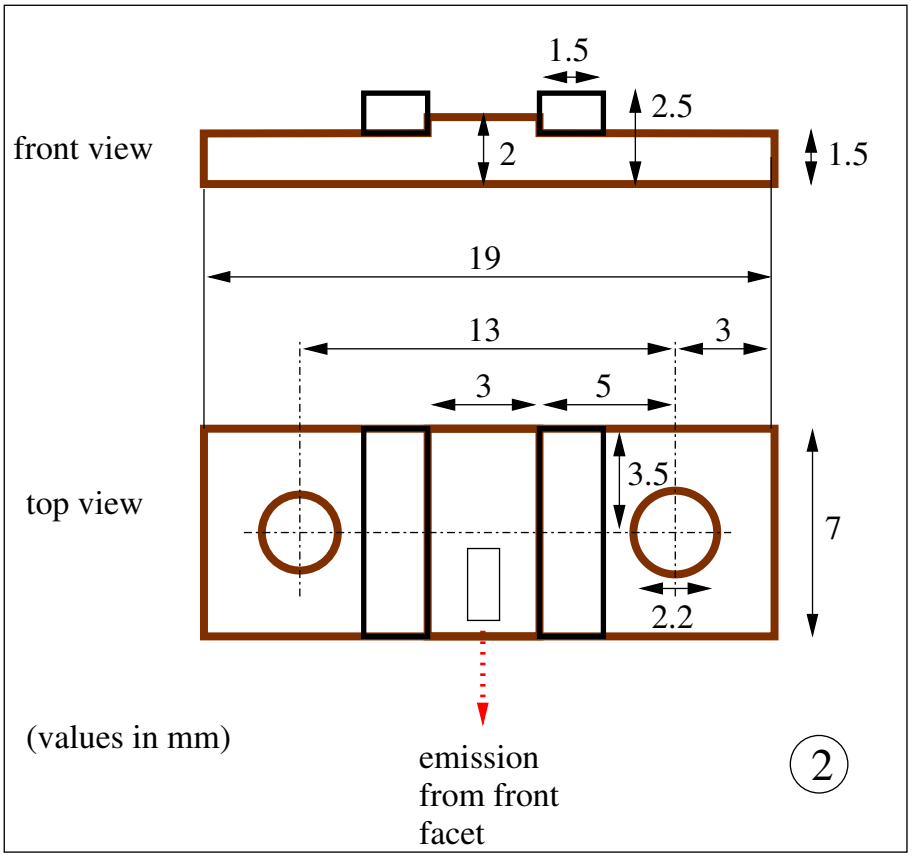

Figure 6.7.: NS mounting.

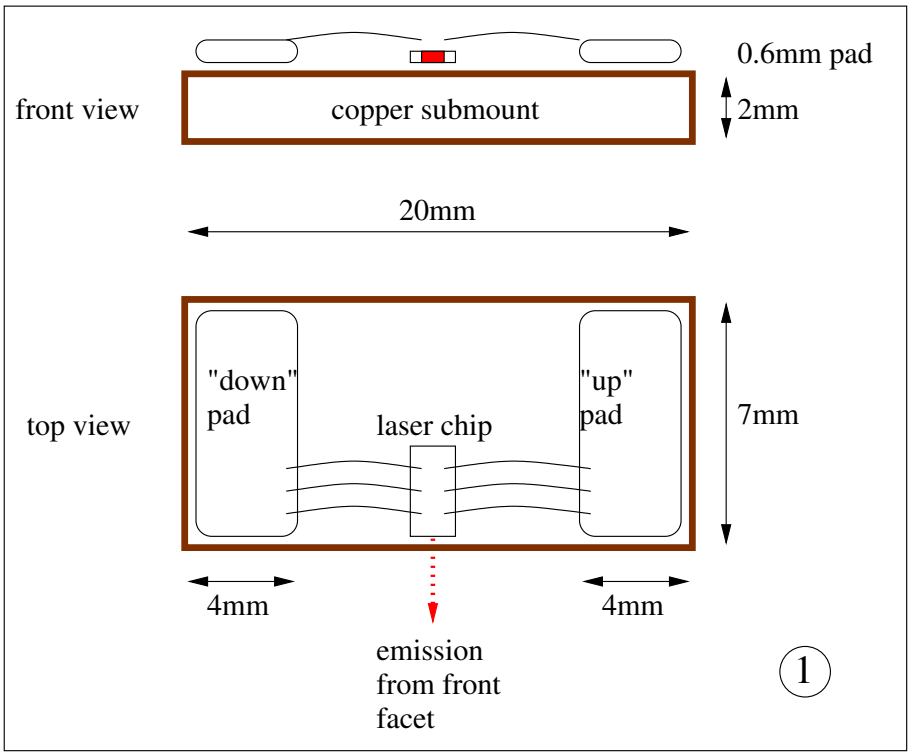

Figure 6.8.: ST mounting.

7. Maintenance

In this chapter the maintenance procedures for the installation of a QCL in the HHL housing and Starter Kit components calibration are presented.

> IMPORTANT:
> The maintenance procedures included in this chapter have to be followed carefully by expert users only. Delicate operations may result in permanent damage to the laser if not carried out properly.

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7.1. Laser installation in LLH housing

In this sections are presented guidelines for manipulating the laser safely and the procedure for exchanging the laser in a LLH housing.

7.1.1. Handling

The laser should always lay flat, with its vertical axis upwards, on a flat and stable surfaces, without touching anything around its circumference. When mounted in an appropriate and stable holder, it can be operated in any orientation.

CAUTION:
Do not position the laser upside down. This may damage the bonding wires and possibly the laser itself.

The most delicate parts of a QCL are the laser chip itself and the bonds connecting it to the ceramic pads (see section 1.1.2 for details). Therefore the QCL should be manipulated using tweezers touching the submount, as shown in figure 7.1. Whenever possible, carry the QCL laying flat on a stable surface. Avoid contact of the front facet of the QCL with any object, like the walls of its storage box.

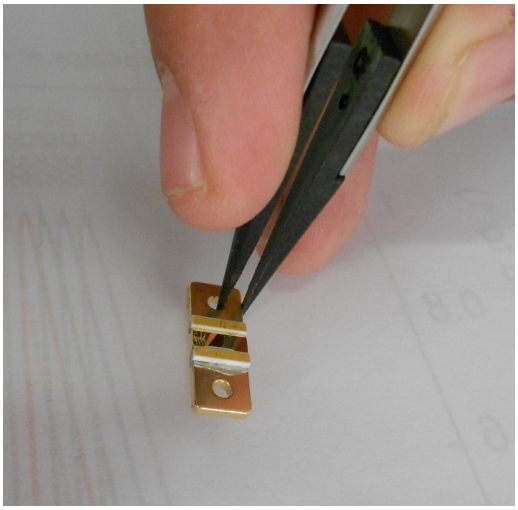

Figure 7.1.: Handling of QCL.

CAUTION:
Do not touch the bonds nor the laser chip itself, as the QCL may be permanently damaged.

CAUTION:
Avoid any dust to deposit on the laser chip or any laser submount item. Malfunctioning or permanent damage to the laser may occur.

7.1.2. Contact set

The contact set shown in figures 7.2 connects the laser active pad to the low impedance line of the LLH through a copper contact, as shown in figure 7.3.

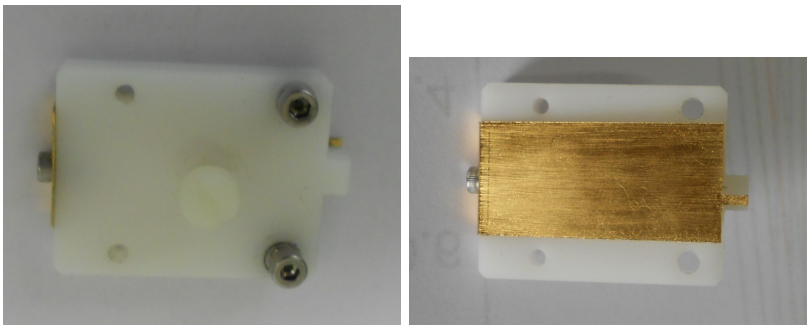

Figure 7.2.: LLH contact set, top (left) and bottom (right).

The laser submount is screwed onto the LLH base copper plate, on which the contact set is screwed to insure electrical contact between the selected pad and the low impedance line, as shown in figure 7.4. The low impedance line (LBI) connects the laser chip to the LDD in pulsed mode, or external power supply in CW mode, through the LLH *laser* and *base* connectors.

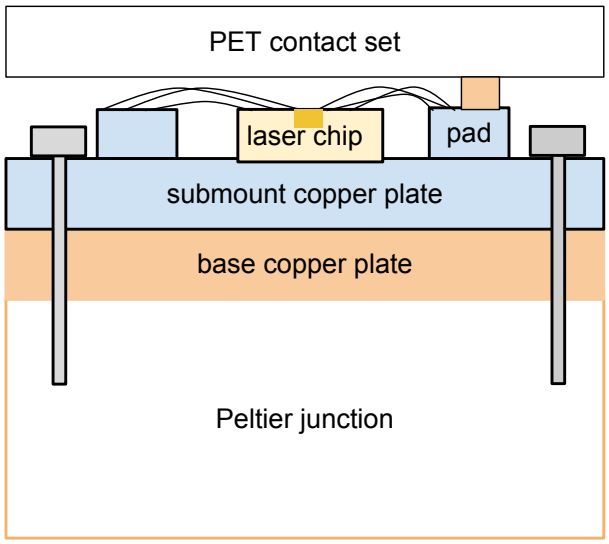

Figure 7.3.: Schematic side view of the laser submount, contact set and LLH.

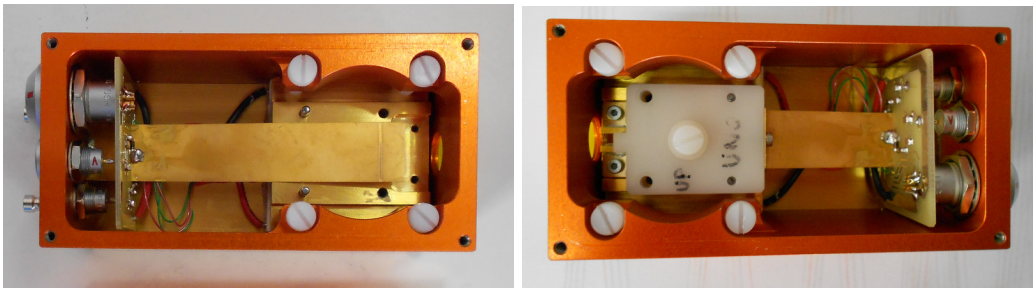

Figure 7.4.: Inside view of the LLH, without (left) and with (right) contact set.

7.1.3. Procedure

This procedure allows the installation of a new laser into the LLH housing.

1. disconnect the LLH and open its cover (2), as shown in figure 7.7

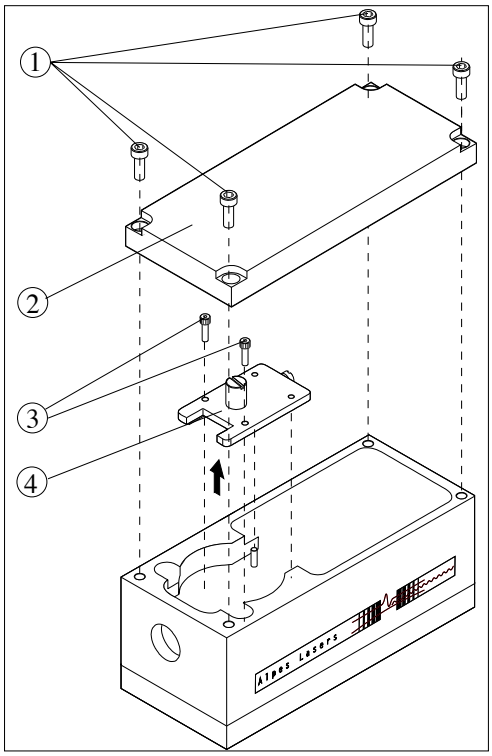

Figure 7.5.: Exchanging the laser in the LLH housing.

2. remove the two screws (3) holding the contact set (4) using a 2mm hex key
3. remove the contact set using the central PET[1] knob, as show in figure 7.6. *Note*: this PET screw is used as a knob, do not remove it.
4. remove the two screws holding the laser submount using a 1.5 mm hex key, as show in figure 7.6
5. remove the laser submount from its storage box using tweezers

IMPORTANT: The guidelines presented in section 7.1.1 must be followed carefully.

[1] PET refers to polyethylene teraphtalate, a common plastic.

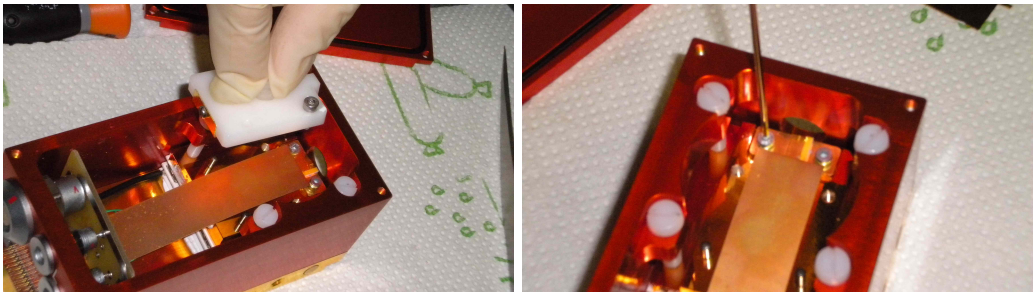

Figure 7.6.: Laser exchange procedure: removing the contact set (left), securing the laser submount (right).

CAUTION:
Do not drop the screws onto the submount. This may result in permanent damage to the laser.

6. secure the laser submount into the LLH with the two dedicated screws; use tweezers to hold the screw in place while screwing with an allen key
7. put the contact set on top of the laser submount into the LLH housing:
   a) use the middle knob to hold the contact set
   b) position the two rear holes above the pins for proper alignment
   c) tighten the two dedicated screws through the front holes
   d) press slightly for good electrical contact
8. use a multimeter to measure the resistance between the *base* and the *laser* connectors. It should lie between 30 Ω and 300 kΩ; no resistance indicates a shortcut, infinite resistance indicates a misconnection[2]. In those two cases, perform step 7 until a good contact is obtained.
9. close the LLH cover

[2]The laser's resistance is measured between the submount copper base and the ceramic pad. The resistance between the *base* and the *laser* connectors on the LLH should be the same as the laser's resistance ($\pm 2\Omega$).

7.1.4. UP and DN contact exchange

Follow procedure 7.1.3, adding those additional steps to step 7:

1. remove the screw (5) located at the back of the contact set, as shown in figure 7.7
2. remove the copper contact (6)
3. replace it with the copper contact supplied by ALPES LASERS with the new laser
4. tighten back the screw (5)

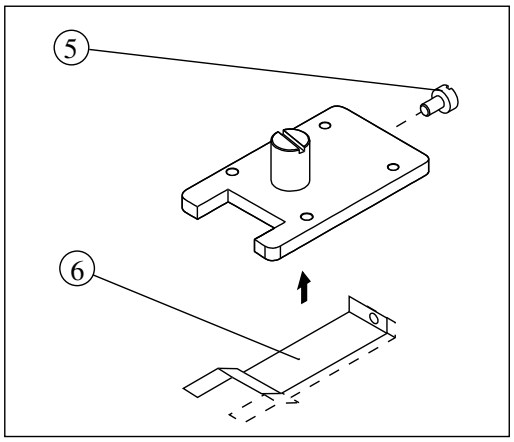

Figure 7.7.: Exchanging the laser submount UP and DN contact (right).

7.2. Calibration procedures

In this section the calibration procedures for the TPG and TCU are detailed. In both cases a few preliminary steps must be followed:

1. Switch off the device.
2. remove the TPG or TCU cover (refer to figure 7.8):
   a) Pull off the light gray plastic pieces of the side of the front and back plates.
   b) Lift off the light gray plastic shades form the side of the box, which gives access to the screws holding the top and bottom covers.

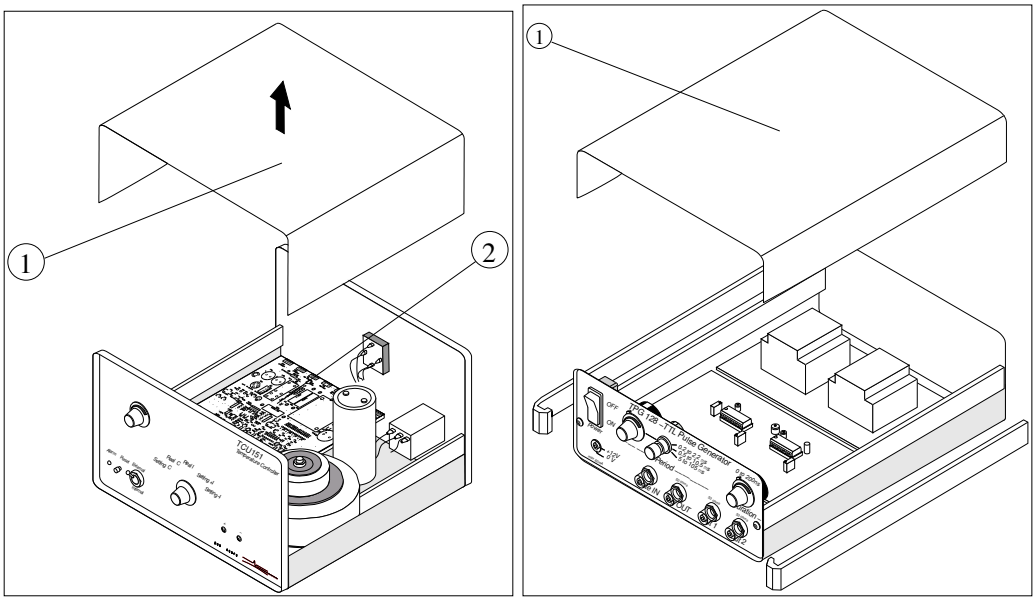

Figure 7.8.: TPG (left) and TCU (right) cover removal.

3. Switch on the device.

DANGER
Contact with AC line potential can cause death or serious injury If work on live electrical circuits is required, use all appropriate precautions and hot work procedures required at your location.

7.2.1. TCU interlock level setting procedure

This procedure allows to set the TCU interlock level.

1. switch off the TCU
2. unplug the power cable
3. remove the cover to access the main board following step 2 of the previous procedure.
4. locate the *J9 Interlock* connector
5. position the associated jumper according the desired type of interlock:
   - NC (normally closed): pins (4) and (5)
   - NO (normally open): pins (3) and (4)

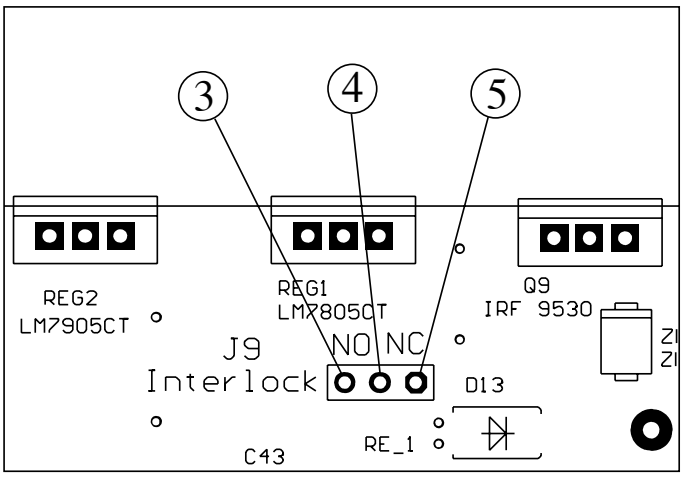

Figure 7.9.: TCU board J9 Interlock connector.

7.2.2. TCU calibration

This procedure must be followed for a general calibration of the TCU command knobs and selectors. Refer to section 5.1 for TCU front panel commands description.

> IMPORTANT:
> The TCU is calibrated in factory. This procedure is not a routine procedure and must be performed by experts only.

Material needed

- Voltmeter HP3458A or equivalent.
- Voltage source Keithley SMU237 or equivalent.
- Precision resistor 100 Ohm 1% or better.
- Cable: LEMO 6 poles female 6 bananas female (LEMO connector: LFGG.1B.306.CLAD72Z, LEMO handler GMA.1B.065.DG).

> DANGER
> Contact with AC line potential can cause death or serious injury If work on live electrical circuits is required, use all appropriate precautions and hot work procedures required at your location.

Procedure

1. Power off the instrument.
2. Open the TCU top cover to access the main board.

3. **+5V/-5V power supply check.**

CAUTION:
Do not connect the signal IN-34 V DC (connector J1 (3)). This may result in permanent damage to the Peltier junction.

a) Check that the input impedance between +5V/-5V and GND have the following values:
   - **TP1** (4) - **GND** (5): $>$ 2.5 kΩ.
   - **TP2** (6) - **GND** (5): $<$ 4 kΩ.

b) Power on the instrument.

c) Check that the **+5V/-5V** power supply voltage have the following values:
   - **TP1** (4) - **GND** (5): 4.95 to 5.2 V.
   - **TP2** (6) - **GND** (5): 4.95 to 5.2 V.

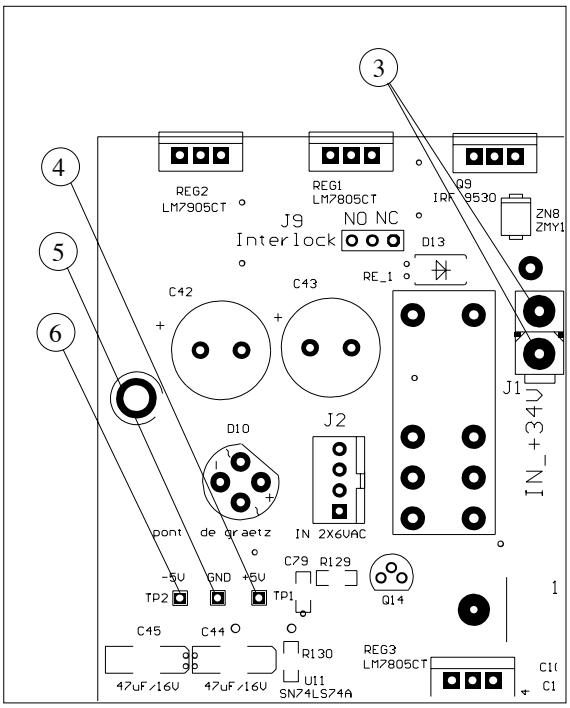

Figure 7.10.: TCU main board (zoom I).

4. Sensing level and range adjustement (refer to figure 7.11)

   a) Replace the cable connected to ***J8*** (4) with the 100$\pm$1 Ω resistor. *Note*: the precision (gold band on the resistor) is important. Connect one side of the resistor to pins 1 and 2, the other side to pins 3 and 4.

   b) Measure the voltage on ***Zn3/R10*** (3): the value should be - V = 1.22 to 1.25V.

   c) Measure the voltage at the intersection of ***R19/R35*** (5): the value should be V=100mV, adjustable with the ***P1*** (2)) knob.
   Note: If the range is too small, replace the resistor ***R1*** (1) = 1.3kΩ with 1.4kΩ.

   d) Set the selector (9) to display ***Real °C.***

   e) Adjust the trimmer **P6** (6) in order to obtain the value of ***000*** °C on the screen (8).

   f) Vary the Temperature Reference by using the ***Set Temperature*** 5 turns knob (7) located on the front panel. The range displayed should be ***-074 to + 074***.

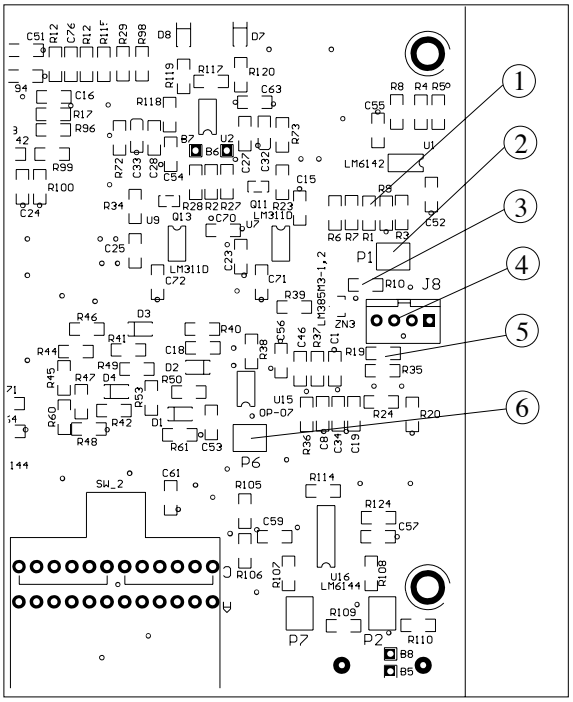

Figure 7.11.: TCU main board (zoom II).

5. Temperature Reference offset adjustment (refer to figure 7.12)

   a) Adjust ***B13*** (3) to ***0.000*** with ***P3*** (4)

   b) Set the temperature with the ***Set Temperature*** knob (Fig.40 (7)) to +5 °C
   ↪ The temperature reference signal B13 should be ≥4.3V

   c) Set the temperature with the ***Set Temperature*** knob (Fig.40 (7)) to -5 °C
   ↪ The temperature reference signal B3 should be ≤4.3V

   d) Check the switch range by setting the Temperature Reference at + 2 °C and -2 °C:

      B7 = -5V and +5V

      B6 = +5V and -5V

   e) Check the output voltage of the transistors
   ↪ The signals on ***R78*** and ***R81*** should toggle simultaneously with the inversal signals on **R79** and **R80**

CAUTION:
The signals B6 and B7 (2) must never be at 0V simultaneously. This may result in a short-circuit

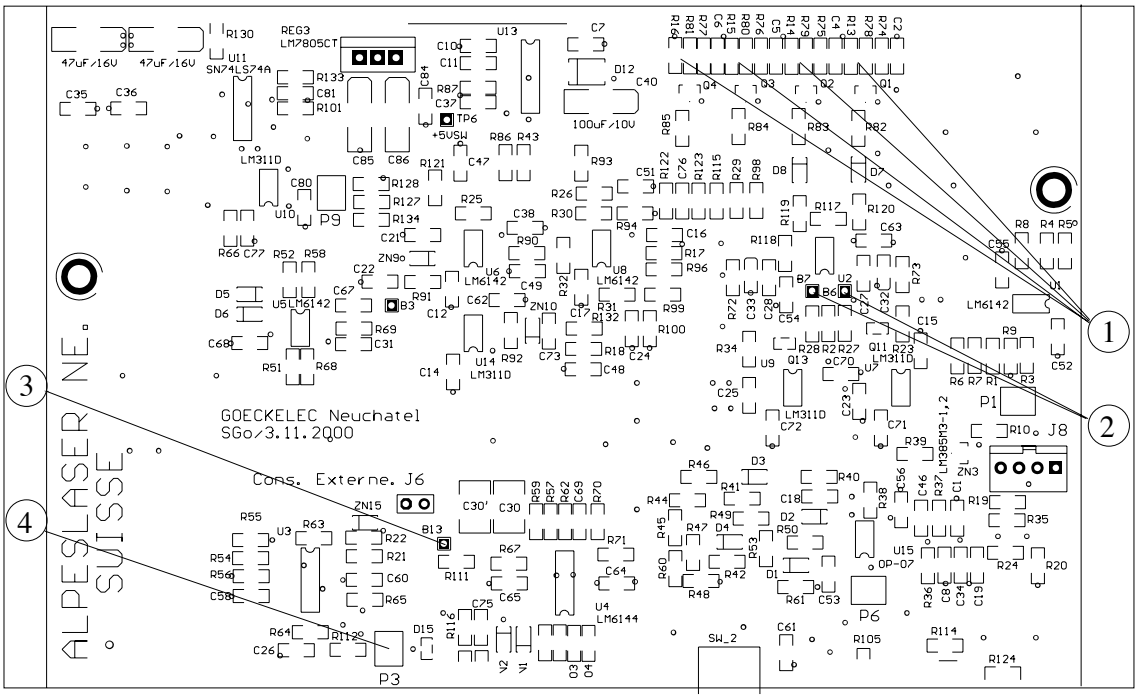

Figure 7.12.: TCU main board (view I).

6. Oscillator check (refer to figure 7.13): measure the frequency on the ***pin 7*** of ***U13*** (1); the value must be 28KHz + /- 3KHz.

7. Current/Voltage ratio adjustment (refer to figure 7.13)
   a) Adjust the trimmer ***P4*** (6) in order to read ***B4*** = 0.6V (4).
   b) Set the selector (5) to mode ***Setting +I***: the LCD screen should display ***1.00 A***.
      Note: If it is not the case, adjust it with ***P2*** (2).
   c) Adjust the trimmer ***P4*** in order to read **B4** = 3.0 V: the LCD screen should display ***5.00 A***.

      Note: If it is not the case, adjust it with ***P2*** (2). Example : 0,6 V $\Rightarrow$ 0,99 A and 3V $\Rightarrow$ 4,99 A.
   d) Set the switch on the front panel to mode ***Setting -I.***
   e) Repeat steps [2] and [4] for ***P5*** (7) and ***B5*** (3).

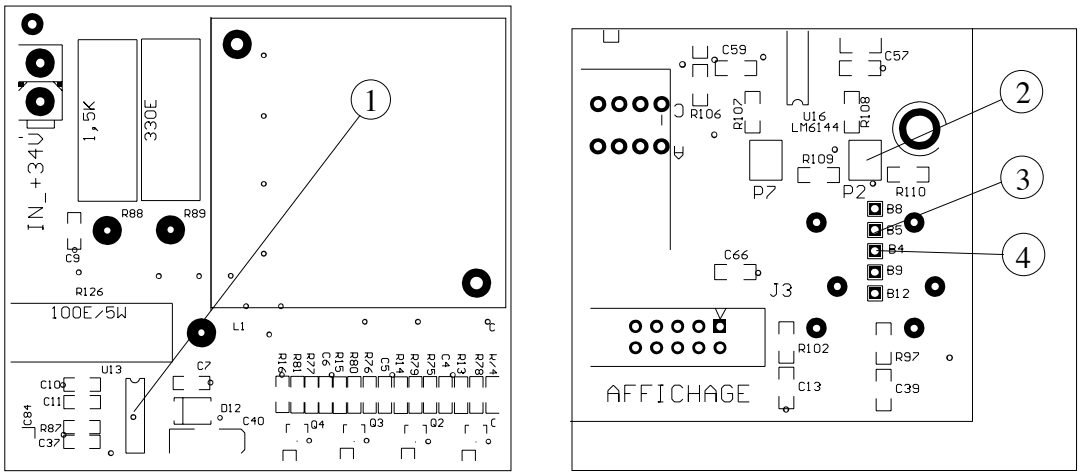

Figure 7.13.: TCU main board, oscillator check (left), current/voltage ratio adjustment. (right).

IMPORTANT:
For the remainder of this procedure, limit the positive current to 1 A and the negative current to 1.2 A using the 5 turns knob.

8. Temperature limit threshold
    a) Measure the voltage on ***pin 2*** of ***U10*** (1): the value should be: 0.7V (= 70 °C) (If needed, adjust it with the trimmer ***P9***(2)).
    b) Power off the instrument.
9. Starting the power section of the instrument.
    a) Remove the 100 E reference resistor from ***J8*** (4) and plug the output cable ***J8***.
    b) Plug the external cable into the LLH100, and verify that the Pt100 is properly mounted in the latter.
    c) Use an external power supply (0-30VDC/3A) to simulate the internal power supply.
    d) Limit the current to 200 mA and connect it to main board ***J1*** connector (3).
    e) Power on the instrument and the external power supply.

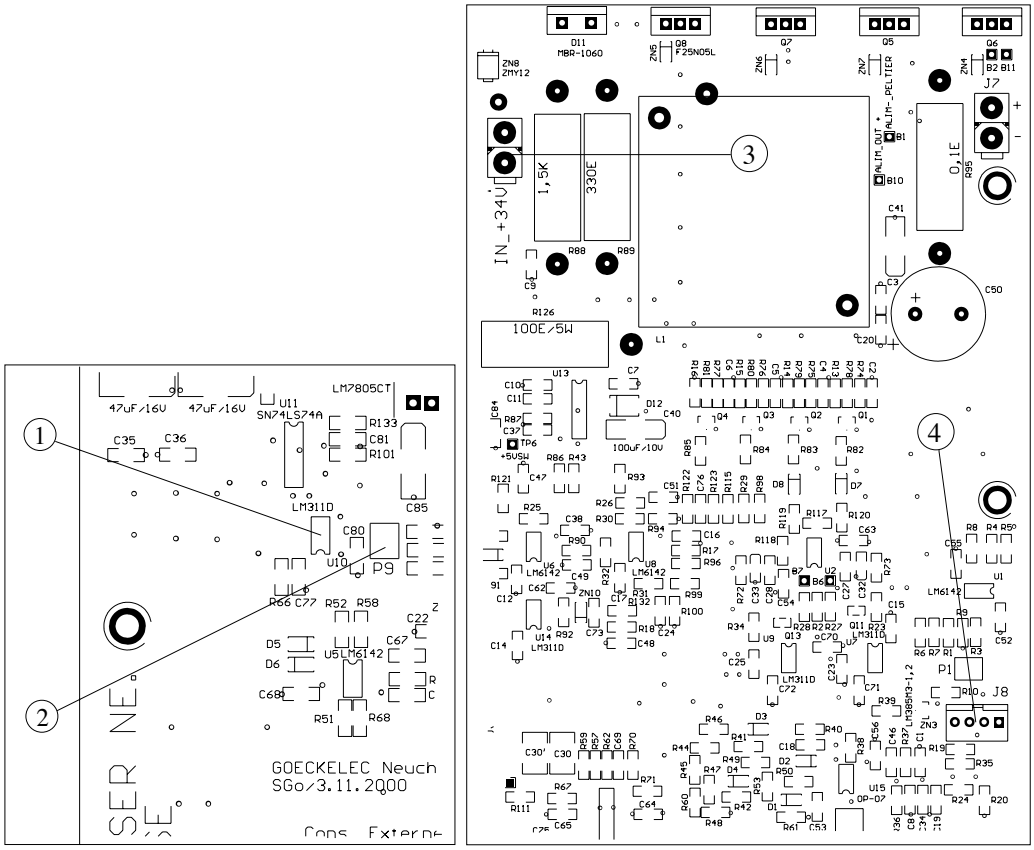

Figure 7.14.: TCU main board (zoom III and IV).

10. Current adjustment

    a) Set the selector (3) to mode ***Setting °C*** and adjust the temperature value to 25 °C by means of the ***Set Temperature*** 5 tuns potentiometer P8 (2).

    b) On the external power supply, rise slowly the voltage to 30 V and the current to 1.5 A: the tension should stabilize at 30 V.
    Note: If the current is too high, stop the test and verify the transistors ***Q1*** to ***Q4*** (1) and their associated resistors. There might be a soldering problem. In this case, fix it and repeat the procedure from step 5.

    c) Set the selector (3) to mode ***Real I***: the displayed value should be $\leq$ 1A.

    d) Set the selector (3) to mode ***Real °C***: the value displayed should tend to the defined value. If not, adjust ***P3***.

    e) Wait for a certain time and check the Peltier temperature with a thermometer

    f) Set the selector (3) to mode ***Setting +I***.

    g) Increase the limit of positive current to 3.5A by means of the ***+I*** trimmer (4) located on the front panel.

    h) Increase the limit of negative current to 5A by means of the ***-I*** trimmer (5) located on the front panel.

    i) Change the temperature reference to -25 °C and check the displayed current.

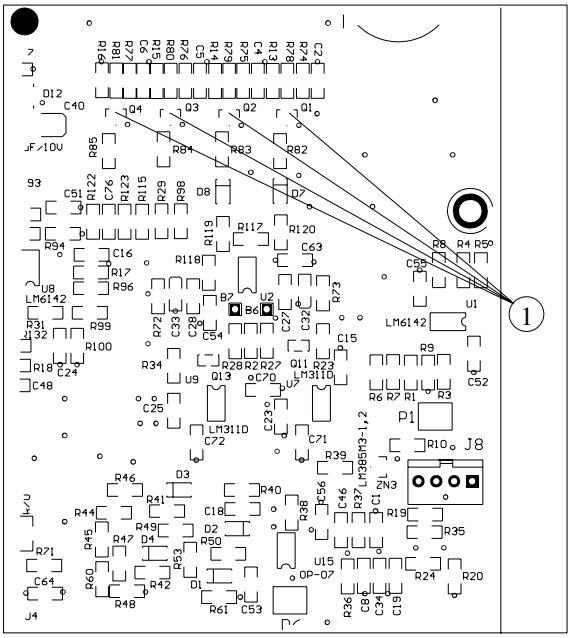

Figure 7.15.: TCU main board, current adjustment.

11. Temperature limit testing
    a) Decrease the temperature limit threshold from 0.7 V to 0.3 V.

       *For more details, see **Temperature limit threshold** on page 89.*

    b) Increase the temperature reference to 35 °C.

       ↪ *When the threshold is overpassed, the red LED (1) in front panel should light up.*

    c) Wait the real temperature drops 10 °C below the threshold.

    d) Reset the instrument with the ***RESET*** button (2).

       ↪ *The red LED (1) should turn off.*

    e) Reset the temperature limit threshold to 0.7 V. *For more details, see **Temperature limit threshold** on page 89.*

12. Monitoring: check the output voltage on the rear instrument BNC connector (5). *For 35 °C, the voltage should be 350 mV.*

13. External reference:
    a) connect an external power supply to the ***External Reference*** BNC connector (6).

    b) Set the voltage to 3.5 V.

       Set the switch ***External/Internal*** (3) to ***External***.

       Set the selector (4) to mode ***Setting °C***.

       ↪ *The temperature displayed (2) should be 35 °C.*

       Set the selector (4) to mode Real °C.

       ↪ *The temperature displayed (2) should follow the reference temperature.*

7.2.3. TPG calibration

This procedure describes the steps to be followed to calibrate the TPG front panel knobs settings. Refer to figure 5.2 for the TPG commands description.

IMPORTANT:
The TPG is calibrated in factory. This procedure is not a routine procedure and must be performed by experts only.

DANGER
Contact with AC line potential can cause death or serious injury If work on live electrical circuits is required, use all appropriate precautions and hot work procedures required at your location.

[1] Verify the +5 V power supply.

[2] During the first test, set all knobs and adjustable capacitors to their medium values.

[3] Adjust to the knob ***50 ns adj*** (3) in order to obtain a 500 ns long pulse on ***TP2*** (2).

[4] Measure the pulse period through the boxTrigOut output connector using a scope.

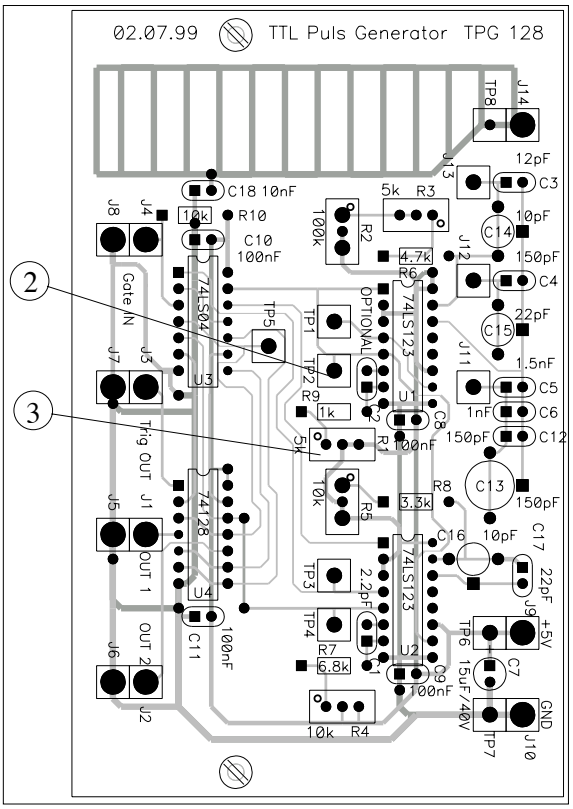

Figure 7.16.: TPG main board (view I).

[5] Select the range 5 μs to 105 μs on the period selection knob. Turn the 10 turns adjustment knob to its last position. Adjust the adjustable capacitor ***max 105 μs adj*** (4) in order to obtain a 105 μs long period.

[6] Turn the 10 turns adjustment knob to its first position. Ajust the pot ***Period min adj*** (1) in order to have a period of 5 μs.

[7] Repeat steps 5) and 6) in order to obtain 105$\pm$1 μs and 5$\pm$0,1 μs for the two settings of the ***Period*** knob.

[8] Choose the range 0.2 μs to 2.2 μs. Turn the 10 turns adjustment knob to its last position.. Adjust the ***max 2,2 μs adj*** capacitor (2) in order to obtain a period of 2.2 μs.

[9] Turn the 10 turns adjustment knob to its first position. Check that the period is 200 ns. If this is not the case, re-adjust the pot **50 ns adj** (5) in order to obtain 200 +/-20 ns. (In general, it is not possible to go below 210 ns).

[10] Choose the range 0.5 μs to 10.5 μs. Pot 10 turn ***Period*** on 10. Adjust capacitor ***max 10,5 μs adj*** (3) in order to have a period of 10,5 μs.

[11] Turn the 10 turns adjustment knob to its first position. Check the that period is of 0.6 +0/-0.1 μs.

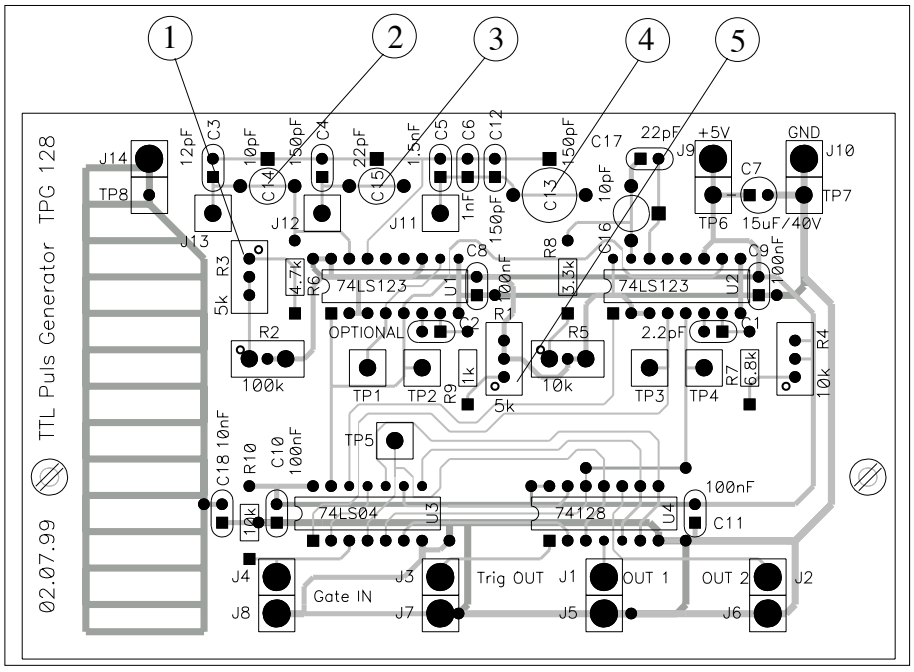

Figure 7.17.: TPG main board (view II).

clearpage

[12] Connect oscilloscope on the ***Output*** connector. Load with a 50Ω . Choose a repetition period of about 5 μs.

[13] Turn the boxduration adjustment knob to its last position. Adjust the ***Max duration*** capacitor (2) to have an output pulse of 200 ns +/-5 ns.

[14] Turn the boxduration adjustment knob to its first position. Adjust the pot ***Out 0ns adj*** (1) in order that the output pulse is 0ns. The pulse is 0 ns long when its shape is triangular with an amplitude of 1,1 V (half of the maximum value).

[15] Repeat points [13] and [14] until the values are OK.

[16] Check the operation of the boxGate in external mode. A signal is present on the ***Output*** output connector if the input ***Gate in*** open (high TTL level) = ***gate*** open; no signal is measured on the ***Output*** output connector indicates a short circuit on on input ***Gate in*** (low TTL level) = ***gate*** closed.

[17] Check that the +12 V is present on the Lemo 00 connector (+12 V on the centre connector).

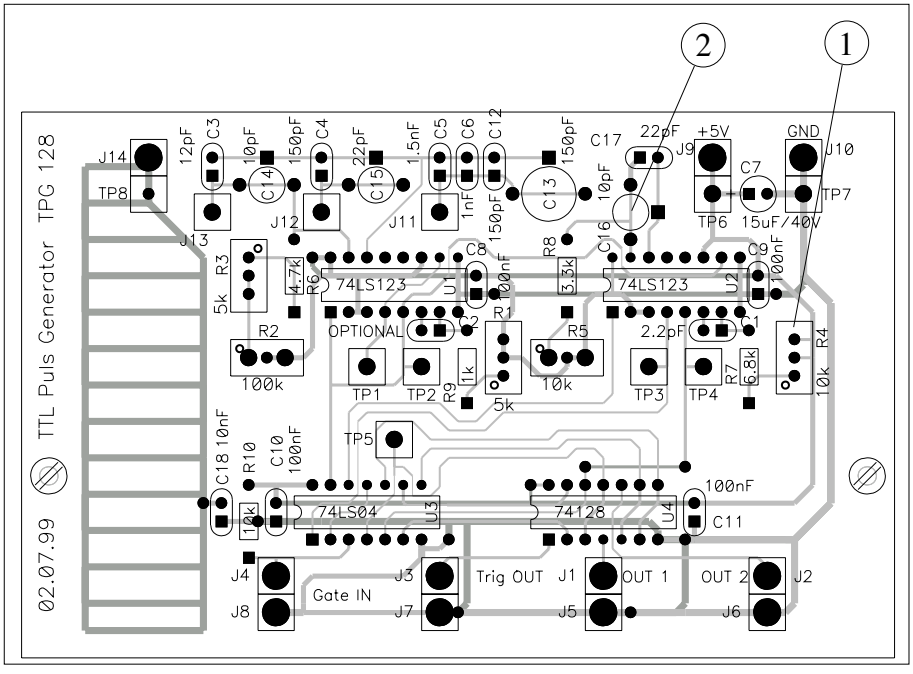

Figure 7.18.: TPG main board

A. QCL theory and application notes

A.1. QCL wavelength range

Unlike standard bipolar semiconductor lasers (e.g. 1.55μm telecom devices), for which the emission wavelength is closely related to the band gap energy, the QCL transition consists in the transition of an electron inside sub-bands, from one upper quantum well level to a lower quantum well level.

A series of potential wells and barriers for the electrons are built by using two different semiconductor materials (InGaAs and AlInAs), These wells and barriers are so thin that the electrons are allowed only a discrete set of energy levels, similar to the orbitals of an atom. The positions of the allowed energy levels are determined by the thicknesses of the wells and barriers, making it possible to define a wide range of laser transitions by using only one material system (InGaAs/AlInAs grown on InP). This range is limited by the intrinsic absorption of the material and the potential difference between the wells and barriers.

All QCLs are grown using the same materials, but with layers of specific thicknesses and compositions to obtain a given emission wavelength, which is determined by the geometry of the semiconductor layers that compose the laser crystal.

A.2. QCL electrical response

The QCL can be modeled with a combination of one resistor and two capacitors. R1 increases from a higher resistance at low biases to 1-4 Ohms at the operating point. The resistance at low bias varies from 10-20 Ω to 10^2 kΩ for 10 μm and 4 μm wavelength QCLs respectively. C1 is a 100 pF capacitor (essentially bias independent) between the cathode and the anode coming from the bonding pads. C2 depends on the laser mounting; typically, C1<100 pF in the LLH.

As an example, the values given below apply for a 10μm laser wavelength. *Note*: Voltage and resistor values may vary according to the type of laser.

R1 : . . . . . 10 to 20Ω when a voltage of less than 4 to 6 Volts is applied

R1 : . . . . . 1 to 4Ω up to 10 - 12 Volts

R1 : . . . . . 10 to 20Ω over 12 Volts, after which the laser no longer operates

C1 : . . . . . 100pF, capacitor between the anode and the cathode

C2 : . . . . . $<$100pF, depending on your mounting of the laser

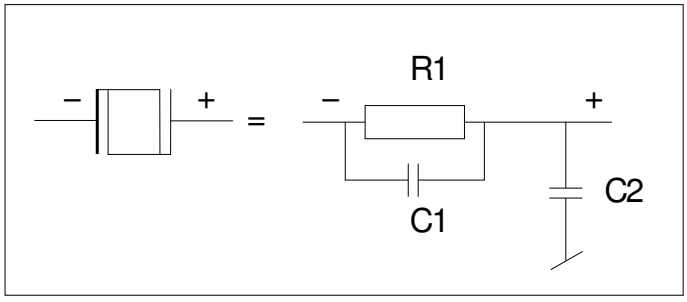

Figure A.1.: Electrical model for QCL.

B. Operations for advanced users

In this section, tips for advanced users are provided for specific application. It is not recommended to perform those procedures in normal operation conditions.

IMPORTANT:
The operation instructions contained in this section must be performed by expert users only, as permanent damage to the laser may occur if not manipulated correctly.

B.1. Direct QCL voltage

These connections give direct access to the voltage of the laser.

IMPORTANT:
Direct voltage measurement of the QCL must be performed by experts only and agreed upon with ALPES LASERS.

The "L" connection is connected AC coupled to the cathode of the laser through a divider by ten. The end of cable must be 50Ω terminated for accurate measurement. The "B" is connected the same to the anode of the laser (Base Receptacle).

By using the math trace of an oscilloscope showing the "L" channel minus the "B", one can get the voltage on the laser. This measurement is more accurate than the information obtained from the LDD.

Note: the cables are not included in the Starter Kit but can be supplied by ALPES LASERS.

B.2. Soldering wire bonds from laser chip to submount

IMPORTANT:
Soldering bonds to the carrier is a delicate operation. Contact ALPES LASERS before attempting this operation.

As the QCL chip itself is soldered, and the contact pads on the ceramics are made out of gold, it is not possible to use a normal Lead-Tin solder: the temperature is too high, the solder will destroy the gold contacts by forming an alloy. ALPES LASERS recommends the use of pure Indium for soldering, in the form of paste of microscopic beads in flux.

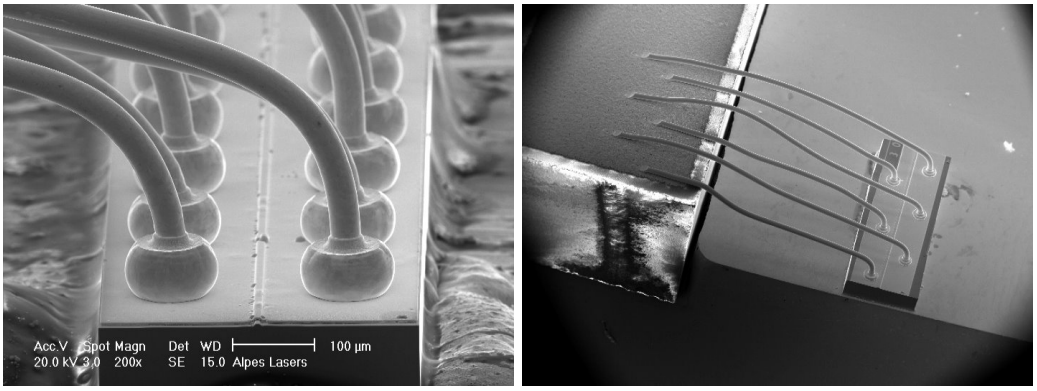

Figure B.1.: Laser chip wire bonds.

It is of highest importance to never touch any part of the laser chip itself (especially not the facets) nor the bonds, as this may result in fatal damage to the QCL. Solder with a very fine tip solder iron at about 170°C, only at the corner of the contact pad which is most distant from the bonds and the chip, using only very thin and flexible wires.

B.3. Bias-T circuit for pulsed lasers

Since tuning of a QC laser is done by changing the temperature of the active zone, the DC bias current can be used to control the emission wavelength of the laser via its heating effect. The bias-T therefore allows for electrically controlled rapid scanning of the emission wavelength.

B.3.1. Principle

Since tuning of a QC laser is done by changing the temperature of the active zone, a DC bias current can be used to control the emission wavelength of the laser via its heating effect. Tuning can also be achieved by changing the temperature of the whole laser, but at a much lower speed, due to the high thermal capacity of the laser submount and base. A bias-T circuit allows for a quick scan of the emission wavelength because the laser emission response is much faster, as only the active zone is heated.

The DC current is drawn from the external power supply and applied to the laser in addition to the pulsed current. It is recommended to apply currents of up to 0.1kHz, but several customers have used the bias-T at frequencies of up to several kHz.

Laser lifetime

Heating of the active zone will increase thermal stress of the laser, therefore the expected lifetime will decrease more rapidly compared to increasing the temperature of the laser submount and base. If operation at only a fixed wavelength is needed, this should be adjusted with the overall temperature control.

B.3.2. Connection

The bias-T circuit can be integrated in the TPG. The circuit included in the LDD pulser unit is controlled by the twisted black and yellow wires of the control cable with the CPL cable.

B.3.3. Procedure

- Since the input stage of the bias-T is a bipolar transistor, applied voltage must be higher than about 0.6V to start bias current. The input stage has a voltage limit of 2.6V, but the laser itself may be destroyed at lower bias-T control voltage, therefore the maximum rating has to be agreed with Alpes Lasers SA.

- the laser should be operated initially at lowest possible temperature Since a bias-T only allows to heat the laser, the emission wavelength can only be increased (or emission wavenumber decreased), and output power will decrease

with increased bias current, due to the additional heating. This reduces the number of lasers available for reaching a given emission wavelength.

CAUTION:
Applying a high bias current may destroy the laser due to thermal roll-over. Bias-T setup must be performed by instructed personnel and approved by ALPES LASERS.

- The optical output power must be monitored when setting up the bias-T to make sure the thermal roll-over is not reached. Temporary increase of the pulse current must always result in increased optical power output, otherwise the DC bias current is already too high.
- As a rule of thumb, the overall dissipated power (sum of DC bias current dissipation and pulse current dissipation) must never be higher than the average dissipated power given by the highest current / voltage / temperature combination specified in the datasheet.
- The average dissipated power for a given pulse current I, pulse voltage U, and duty cycle d is given by $d \times I \times U$, whereas the dissipated power due to a bias current IB is given by $IB \times U$. (U is the voltage on the laser, but it is safe for this calculation of bias current dissipation to use the voltage on the LDD pulser input.)

B.3.4. Gas concentration measurement

The goal of this procedure is to calibrate and optimize the laser spectrum as a function of temperature and current. A spectral scan of the laser is generated over a wavelength region defined by the scan rate of the laser versus current (cm-1/A, a basic property of the laser). A 60 mA range might be equivalent to 1.2 cm-1 of wavelength change in the laser. The ALPES LASERS datasheets provide a few discrete settings that were measured with a different equipment, which can be used as starting points, but the curves obtained with the following procedure are to be used to acquire the real gas data.

Prerequisites

- Using short pulses and "bias-T" to scan wavelengths
- User has appropriate short pulse generation electronics, cooler control/drive electronics, gas cell(s) and photodetector
- User has and understands ALPES LASERS datasheets for the device to be used

Procedure

1. set the temperature to 15^{o}C so that any moisture inside the package does not condense on the laser chip
2. Use current settings as indicated in the ALPES LASERS datasheet
3. start the laser: the powermeter (if installed) should indicate some power dissipation
4. set the temperature to allow the highest frequency (shortest wavelength) of interest to be emitted
5. Reset the current to settings appropriate for that temperature and wavelength, then reduce it a little bit further - but not below threshold (so you still see energy on the detector)
6. put a gas cell between laser and detector and verify that you can still see the laser energy on the detector; take note of the amplitude of the detector signal.
7. Turn on the bias T current to a low value (typically 0.001A) and record the detector signal
8. repeat at 0.001A increments of bias-T current recording values for each increment until 0.060 A is reached (or some other value that has been discussed/agreed with ALPES LASERS) If the temperature and pulse current starting points were right, the line of interest should be visible in the data when plotted. If not, perform the same procedure with new temperature and pulse current settings.
9. Continue to optimize the temperature and drive parameters
    a) Adjust the pulse length lower and higher and repeat the scan; thus learn about the effect of these parameters on power and laser linewidth
    b) If possible, repeat the measurement with a gas cell with the target gas at low pressure (1 Torr). This will narrow the line greatly and allow to consider the apparent spectral resolution of the laser itself under the drive conditions and to learn whether the driver has any ringing or double pulsing (which will make the line width seem higher).

B.4. CW modulation

To operate a laser in CW mode, an AC signal is added to the DC current. It is recommended to modulate the external power supply directly, within the parameter range specified in the ALPES LASERS datasheet. If this is not possible, an additional modulated source must be used, like a waveform (ramp) generator for example.

Interface circuit

To reduce cross-talk with other system components and to improve mechanical stability, this interface circuit should be installed into a small metal box with only the connectors accessible, as shown in figure B.2.

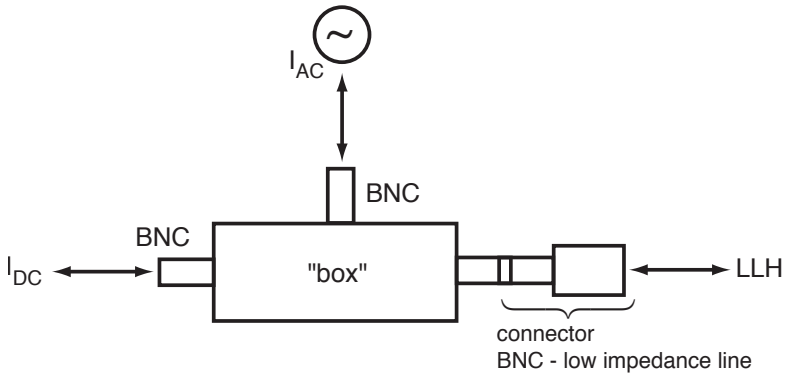

Figure B.2.: Interface circuit for CW laser modulation.

Connectors for the LLH with a BNC plug are available for CW laser operation, ALPES LASERS provides the CIL cable pinout, the adaptor must be made by the user. It is center positive, shield negative, and can directly be connected to a stabilized DC supply; make sure the polarity is correct and limits as specified in the datasheet are set.

B.4.1. External power supply protection

To prevent current modulation to go back to the external power supply, an RLC circuit needs to be added (see figure B.3). The values of R_{AC}, L, C depend on the modulation frequency, the AC source and (to some extent) on the QCL.

Rule of thumb for L

As the impedance $X_L = 2\pi f L$ of the inductivity should be much higher than the dynamic resistance X_Q of the laser to block the AC component from the DC supply, applying $X_L > 100 X_Q$ leads to roughly $L > 16 X_Q / f$.

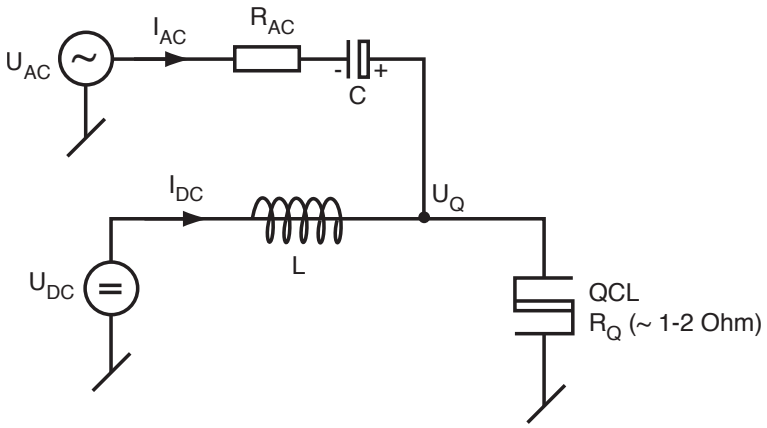

Figure B.3.: RLC circuit for external power supply protection.

In general, X_Q is of the order of 1..2 Ω. For a modulation frequency of 10kHz, L should therefore be of the order of 3mH or larger.

rules of thumb for R and C

To prevent the AC source from dominating or reverse biasing the current through the QCL, $U_{AC} < U_Q$ must always be given (in absolute values). Furthermore, as the AC voltage source together with R_{AC}, C is forming a current source, to prevent variations of QCL dynamic resistance X_Q to influence the AC current, $R_A C + X_C >> X_Q$ must be guaranteed. As the generator for U_{AC} will have an impedance Z_{AC}, impedance matching demands for $R_{AC} + X_C + X_Q = Z_{AC}$. Putting these constraints together leads to $I_{AC} < U_Q/Z_{AC}$.

For the capacitor C to let pass the AC current, $2\pi R_{AC} C > 1/f$ must be true, and with $X_C = R_{AC}/100$ or smaller to make sure that the impedance of the AC current source does not vary too much with frequency, it follows that roughly $C > 8/Z_{AC}/f$.

For a 50 Ω generator at 10kHz, C should therefore be of the order of 16uF or larger.

Please keep in mind that such high capacity components may have a remarkably high inductivity, so it may be useful to put a second capacitor of small value (some nF, Tantalum or similar non-polarized type) in parallel to the one calculated before.